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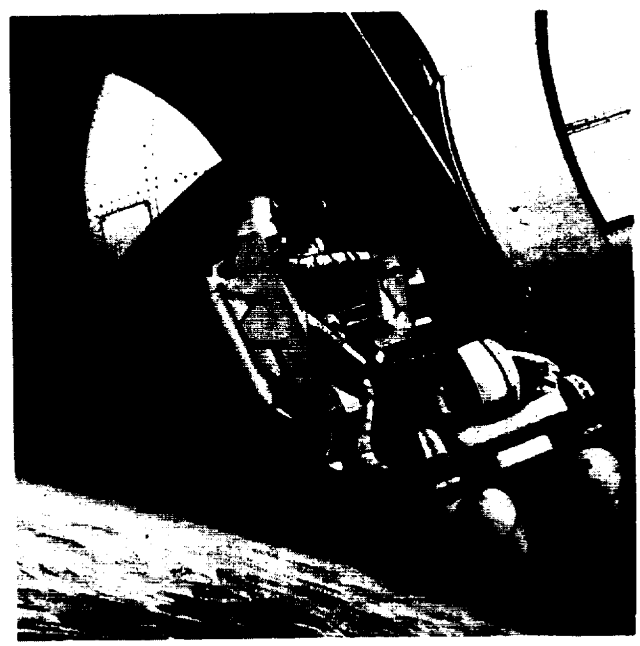
Design and Performance Specification

February 1978

Manned Maneuvering Unit



(NASA-CR-151863) MANNED MANEUVERING UNIT DESIGN AND PERFORMANCE SPECIFICATION (Martin Marietta Corp.) 74 p

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MARTIN MARIETTA

MCR-78-500

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MANNED MANEUVERING UNIT DESIGN AND PERFORMANCE SPECIFICATION

Contract NAS9-14593
Contract Statement of Work
Item Paragraph 3.3.3

Approved

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FOREWORD

This document was prepared as part of the Manned Maneuvering Unit Preliminary Design contract to provide design, performance, and verification requirements which will be used to control a contractor end item as part of a flight hardware contract. This document supersedes and replaces MCR-75-398. The document was prepared by Martin Marietta Corporation and is submitted in accordance with Exhibit "A", Statement of Work, paragraph 3.3.3 of Contract NAS9-14593.

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1.0 SCOPE

This specification establishes the design, performance, and verification requirements for the MMU (Manned Maneuvering Unit) flight hardware for the Space Shuttle Program. The MMU flight hardware end items consist of the MMU and its FSS (flight support station).

2.0 APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, including documents referenced therein, form a part of this specification to the extent specified herein. In the event of conflict between these documents and any other provisions of this specification, the latter shall govern.

2.1 Specifications

2.1.1 NASA

SC-E-0006 December 1, 1972	Manned Spaceflight EV/IV Activity Support Equipment, Functional Design Requirements
SE-F-0044A February 6, 1975 Change 1, (11-1-76)	Filters, Wire Cloth Type, General Specification
SE-R-0006B March 29, 1976	General Specification, NASA-JSC Requirements for Materials and Processes
SE-S-0073C February 14, 1977	Specification, Space Shuttle Fluid Procurement and Use Control
SL-E-0002A September 16, 1974	Specification, Electromagnetic Characteristics for Equipment For Space Shuttle Program
SN-C-0005 March 1, 1974	Specification, Contamination Control Requirements for Space Shuttle Program
SP-T-0023B September 1975	Environmental Acceptance Testing Specification

2.1.2 Military

MIL-A-8625, Amendment 1 March 13, 1969	Anodic Coatings for Aluminum and Aluminum Alloys

2.1.2 Military - cont.

MIL-C-3965D with Supplement 1 dtd. 3/4/68 & Amendment 1 dated 10/29/68	Capacitors, Fixed, Electrolytic (Non-Solid Electrolyte), Tantalum, General Specification for
MIL-C-5541B, Amendment 2 November 30, 1972	Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-C-6021G September 9, 1967	Castings, Classification, and Inspection of
MIL-P-27401C January 20, 1975	Propellant, Pressurizing Agent, Nitrogen
MIL-P-6906B February 24, 1969	Plates, Identification, Aircraft
MIL-S-7742B, Amendment 1 March 15, 1973	Screw Threads Standard, Optimum Selected Series, General Specification for
MIL-T-152B(1) June 6, 1966	Treatment, Moisture and Fungus Resistant, of Communications, Electronic and Associated Electrical Equipment
MS-33540G February 9, 1973	Safety Wiring and Cotter Pinning Specification for

2.1.3 Other

SV767789 May 13, 1977	Battery, S/AD (Hamilton Standard)

2.2 Standards

2.2.1 NASA

JSCM 8080 April 26, 1971 Change 7, (2-1-76)	Manned Spacecraft Design Criteria and Standards

2.2.2 Military

MIL-STD-129G September 1, 1976 Change Notice 1 (1-25-77)	Marking for Shipment and Storage

2.2.2 Military - cont.

MIL-STD-130D March 5, 1971 Change 3 (8-1-73)	Identification and Marking of U.S. Military Property
MIL-STD-462 July 31, 1967 Change 3 (2-9-71)	Electromagnetic Interferences Characteristics, Measurement of
MIL-STD-463 June 9, 1966 Change 1 (3-2-72)	Definition and System of Units, Electromagnetic Interference Technology
MIL-STD-810C March 10, 1975	Environmental Test Methods
MIL-STD-1472B December 31, 1974	Human Engineering Design Criteria for Military Systems, Equipment and Facilities

2.2.3 Federal

FED-STD-101	Federal Test Methods, Preservation, Packaging Materials: Test Procedures

2.3 Interface Control Documents

2.3.1 Hamilton Standard

HSD-4-0001-0D-0	EMU/MMU Interface Document

2.3.2 Rockwell International

ICD3-0013-01	MMU/FSS Physical Interface

2.4 Other Documents

2.4.1 NASA

JSC-07572, Rev. G December 1977	List of Materials Meeting JSC Vacuum Stability Requirements
NHB 6000.1B June 1, 1973	Requirements for Packaging, Handling and Transportation for Aeronautical and Space Systems Equipment and Components

2.4.1 NASA - cont.

TMX-64627	Space and Planetary Environmental Criteria Guidelines for Use in Space Vehicle Development

2.4.2 Military

AMRL Technical Report 70-5 April 1972	Anthropometry of Air Force Women
MIL-HDBK-5B September 1, 1971 Chg. 2 (8/31/73)	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-HDBK-17A	Plastics for Aerospace Vehicles
MIL-HDBK-23A	Structural Sandwich Composites
WADC Technical Report 52-321 September 1954	Anthropometry of USAF Flying Personnel - 1950

2.4.3 Industry

ANSI B46.1 1962 Change Notice 2 April 29, 1971	Surface Texture

2.4.4 Other

SV767789	Specification and Assembly Drawing, Battery
SVHS7877	Specification, Optical and Electronic Connector

3.0 REQUIREMENTS

3.1 Performance Requirements - The MMU shall provide an autonomous free flying mobility for the EMU (extravehicular mobility unit). This mobility is required to extend and enhance a crewmember's EVA capability for support of payloads, vehicle contingencies, and rescue operations. The MMU mobility allows unlimited access around the orbiter and nearby payloads, free-space transfer of cargo and personnel, free-space transfer of personnel rescue systems, stationkeeping and tracking, and stand-off positioning for observation, inspection and photography. Typical EVA crewmember tasks to be supported by the expanded capability of the MMU are listed below. (When used in this specification, the term "crewmember" shall refer to either sex.)

a. Payload deployment or retrieval.

b. Adjustment of instruments.

c. Retrieval and replacement of film, coatings, emulsions.

d. Servicing free-flying payloads.

e. Replacement of failed modules.

f. Cleaning sensors and lenses.

g. Assembly of large structures.

h. Routing of cables or lines between discontinuous points.

i. Application of spray coatings.

j. Removal of contamination protective covers.

k. Payload malfunction assessment and corrective action.

l. External inspection of the Orbiter.

m. Documentary photography/television.

n. Transfer of crewmember and equipment in a rescue situation involving a stable orbiter.

o. Transfer of crewmember and equipment in a rescue situation involving a tumbling orbiter.

3.1.1 General Requirements

3.1.1.1 EMU Attachment - The MMU shall be a modular backpack which can be rigidly attached to the EMU such that the crewmember, EMU, and MMU become an integral system as illustrated in Figure 1.

3.1.1.2 Orbiter Attachment - The MMU flight hardware shall include a FSS to provide MMU stowage and environmental protection in the orbiter cargo bay. The FSS shall have the necessary provisions for an unassisted EVA crewmember to unstow, don, egress, ingress, doff, service, and restow the MMU as illustrated in Figure 2.

3.1.1.3 Maneuverability - The MMU shall provide complete six DOF (degree-of-freedom) control authority so that the EVA crewmember can translate in any direction or rotate about any axis. In addition, the MMU shall provide automatic attitude hold so that the crewmember can command the rotational rates to automatically be reduced to near zero and maintained in a null state.

3.1.1.4 EVA Range - The MMU shall have a nominal operating range of 100 yards from the orbiter or other orbiting structure.

3.1.1.5 EVA Duration - The MMU shall operate up to 6-1/2 hours without battery replacement or recharge for a single EVA sortie. Multiple sorties shall be possible with propellant recharge and battery replacement or recharge.

3.1.1.6 Propellant - The MMU shall use noncontaminating, dry gaseous nitrogen as propellant. The MMU shall provide a total delta-velocity of 60 ft/sec plus a 10% reserve propellant.

3.1.1.7 Work Site Support - The MMU shall contain utility power outlets, work area illumination, and equipment attachment provisions.

3.1.1.8 Safety - The MMU shall be designed and certified to ensure that no credible failure could be catastrophic to the EMU, crewmember, or orbiter. Furthermore, the MMU design shall be fail-safe for EVA operations; i.e., any single MMU hardware failure shall leave the combined EMU/MMU in a condition such that the EVA crewmember can return safely to the orbiter via the partially failed MMU without tethers and without assistance from another crewmember. This requirement shall be met by arranging key functional components into two independently operable system sets which normally operate in parallel. Each system set, designated the "A" and "B" systems, shall be isolated from the other in a control logic, electrical, and propulsion sense. Either system set shall be capable of being shut down to isolate a malfunction or failure and the remaining system shall still provide six DOF maneuvering control authority. Therefore, either system set provides a backup maneuvering capability. Components or functions not required for six DOF control need not require a backup capability.

3.1.2 Maneuvering Control Subsystem - The maneuvering control subsystem shall consist of the components necessary for control of thruster firing for maneuvering control and stabilization. These include the hand controllers and the control electronics, logic, valve drive amplifiers, and gyros that are contained in the CEA (Control Electronics Assembly) as shown in Figure 3. Rotational or translational commands shall be generated when the crewmember actuates the hand controllers. These commands shall be p ssed by the control logic to activate appropriate valve drive ampliiiers. The valve drive amplifiers shall energize thruster solenoids to accelerate the man/machine system until the crewmember returns the hand controller to null. The automatic attitude hold control law shall be initiated when the crewmember depresses and releases a switch on the rotational hand controller. The attitude hold control law shall use gyro rate feedback to automatically activate appropriate valve drive amplifiers to drive all rotational rates to null and maintain attitude hold limit cycle operation.

3.1.2.1 Reference Coordinate System - All crewmember maneuvers are referenced to the orthogonal coordinate system shown in Figure 4. The origin of the coordinate system is the center of mass of the combined crewmember/EMU/MMU system.

3.1.2.2 Hand Controllers - A THC (translational hand controller) shall be located on the left arm of the MMU and a RHC (rotational hand controller) shall be located on the right arm. The hand controllers shall also have orthogonal coordinate systems, but with origins within the hand controllers and rotated in pitch relative to the MMU coordinate system by the angle α (see Figure 4) which shall be less than 45°.

3.1.2.2.1 Commands - The hand controllers shall allow the crewmember to initiate commands by displacement of the grip from the centered or null position and to terminate commands by return of the grip to center. The hand controllers shall be spring loaded to return to the centered position when released. The THC shall allow $\pm x$, $\pm y$, $\pm z$ commands and the RHC shall allow $\pm$ roll, $\pm$ pitch, and $\pm$ yaw commands.

3.1.2.2.2 Command Switches - Each hand controller shall contain two sets of isolated command switches for separate inputs to each side of the control electronics.

3.1.2.2.3 Propellant Isolation Switches - Clockwise rotation of the THC grip about its roll axis shall actuate two isolated command switches for separate inputs to each propellant isolation valve.

3.1.2.2.4 Attitude Hold Switch - The RHC grip shall contain a single push button which shall actuate two isolated switches to initiate automatic attitude hold about all three axes.

3.1.2.3 Control Authority

3.1.2.3.1 Translation Commands - The MMU shall respond to individual manual single axis commands along any of the three axes ($\pm x$, $\pm y$, $\pm z$) with a constant acceleration of 0.3 ± 0.05 ft/sec^2 over the combined range of crewmember/EMU/MMU mass properties specified in paragraph 3.2.3.

3.1.2.3.2 Rotation Commands - The MMU shall respond to individual manual or automatic single axis commands about any of the three axes ($\pm$ roll, $\pm$ pitch, $\pm$ yaw) with a constant rotational acceleration of 10.0 ± 3.0 deg/sec^2 over the combined range of crewmember/EMU/MMU mass properties specified in paragraph 3.2.3.

3.1.2.3.3 Simultaneous Commands - The MMU shall respond with simultaneous acceleration about each axis commanded whenever any combination of translational and/or rotational commands (manual or automatic) are present, with one exception. The one exception is that the MMU shall respond only to the manual command whenever *both* manual *and* automatic commands are simultaneously present for the same rotational axis. Reduced acceleration levels are acceptable in response to simultaneous commands.

3.1.2.3.4 Thruster Firing Logic - Simultaneous rotational and translational commands shall be combined to fire thrusters such that propellant consumption is minimized and propellant usage between "A" and "B" systems is balanced.

3.1.2.3.5 Backup Control Authority - The MMU shall provide full six DOF control authority as described above when only one system set is operated except that reduced accelerations in response to single axis commands are acceptable and that rotation commands shall have priority over translation commands when both are present simultaneously.

3.1.2.4 Automatic Attitude Hold - Automatic attitude hold shall be established in all three axes whenever the "initiate conditions" are satisfied. The attitude hold control law shall utilize rate feedback, a rate integrator, and a pulse generator in each axis to automatically control thruster firing as shown in Figure 5(a). The phase plane plot shown in Figure 5(b) illustrates the attitude hold operation. If the rate is above a 0.2°/sec threshold when attitude is initiated, appropriate thrusters come full on until the rate is decreased below the threshold. Thruster activity then ceases and the phase plane displacement origin is established at that point. In the absence of thruster firing, the small remaining rate persists until the vertical switching line is encountered. The phase plane displacement origin is established immediately on initiation of attitude hold if the rate is below 0.2°/sec. When rotation rate is positive and the displacement exceeds the vertical switching line, thrusters are activated to command a negative rate. Negative rates are treated in a similar manner when the opposite switching line is encountered. The net result, in the absence of disturbance torques, will be convergence to a limit cycle bounded by the displacement deadband.

3.1.2.4.1 Initiate Conditions - Automatic attitude hold shall be available whenever rate gyro power is on. First operation of the RHC attitude hold switch after rate gyro power is applied shall initiate attitude hold in all three axes. Thereafter, automatic attitude hold shall be initiated in all three axes whenever the crewmember operates the attitude hold switch.

3.1.2.4.2 Inhibit Conditions - Automatic attitude hold shall be inhibited until the first operation of the RHC attitude hold switch each time rate gyro power is turned on. Thereafter, automatic attitude hold shall be inhibited independently in the roll, pitch, or yaw axis whenever the crewmember issues a manual rotation command for that particular axis. Attitude hold shall be inhibited for all axes whenever rate gyro power is turned off.

3.1.2.4.3 Attitude Displacement Deadband - The limit cycle displacement range shall be field-selectable between ±0.5 and ±2.0 degrees.

3.1.2.4.4 Inertial Drift - The limit cycle zero reference inertial drift from all sources shall not exceed ±0.010 degrees/second.

3.1.2.4.5 Limit Cycle Rate - The MMU angular rate in each axis after full convergence to the automatic attitude hold limit cycle shall not exceed ±0.1 deg/sec in the absence of manual commands. The limit cycle rate in any axis shall not exceed ±0.5 deg/sec when manual translational commands are issued.

3.1.2.5 Cross-Axis Effects - Cross-axis effects from the following sources shall be considered during the design so command authority and consumable usage will not be adversely affected.

a. CG offset;

b. Thruster misalignment;

c. Plume impingement;

d. Thruster magnitude mismatch;

e. Thruster on-time mismatch;

f. Unequal principal inertias;

g. Products of inertia;

h. Residual momentum.

3.1.3 Propulsion Subsystem - The propulsion subsystem shall provide the required translational forces and rotational moments by means of fixed position thrusters located about the crewmember/EMU/MMU center of mass. The propulsion subsystem shall consist of identical "A" and "B" system sets, each of which shall include a propellant storage pressure vessel, fixed position thrusters, regulator, isolation valve, and associated compoments and fluid lines. A functional schematic is shown in Figure 6.

3.1.3.1 Propellant Storage - The MMU shall contain two pressure vessels for propellant storage with the capability of being charged to 4500 psia. The pressure vessels shall be rechargeable during EVA by an unassisted crewmember without removing the pressure vessels from the MMU.

3.1.3.1.1 Propellant - The propellant shall be gaseous nitrogen in accordance with MIL-P-27401, Type 1, Grade A, and SE-S-0073.

3.1.3.1.2 Propellant Capacity - Each pressure vessel shall contain sufficient propellant to provide an equivalent translational ΔV of 36 ft/sec based on an initial combined crewmember/EMU/MMU mass of 20.0 slugs and initial pressure vessel conditions of:

$P = 3{,}000$ psia; $T = 70°F$

decaying to

$P = 250$ psia; $T = -15°F$.

(This sizes the complete propulsion subsystem to deliver at least 60 ft/sec ΔV with 6 ft/sec reserve in each pressure vessel.)

3.1.3.2 Pressure Regulation - The manifold pressure ahead of the thrusters shall be regulated to 200 ± 20 psia during single axis commands as long as the tank pressure exceeds 500 psia. The control authority acceleration levels specified in paragraph 3.1.2.3 are applicable whenever both tank pressure levels exceed 500 psia. An integral relief valve with a nonpropulsive vent shall be included in each regulator to prevent overpressurizing the manifold in the event of a failed-open regulator.

3.1.3.3 Thrusters

3.1.3.3.1 Thruster Triads - Thruster triad assemblies (three thrusters packaged into an integral module) shall be used for ease of installation and maintenance. The thrust vectors of each triad shall form a mutually orthogonal set that intersects at one point. One of these thruster triads shall be mounted on each of the eight corners of the MMU as shown in Figure 7. Figure 7 shows that four of the triads shall be included in the "A" system and four in the "B" system.

3.1.3.3.2 Thruster Response - The thrusters' output shall rise to full thrust within 0.006 seconds of command application and shall be capable of attaining a minimum on-time of less than 0.005 second.

3.1.3.4 Propellant Isolation Valve - Two electrically operated latching valves shall be provided (one for each pressure vessel) to isolate the pressure vessels from the regulators in the event of a downstream component failure.

3.1.3.5 Charging Quick Disconnect - A single charging quick disconnect shall be provided so both pressure vessels may be charged simultaneously through a single line.

3.1.3.6 Toggle Valve - Two toggle valves shall be provided to allow isolation of the pressure vessels after charging is complete.

3.1.3.7 Pressure Gage - Two pressure gages shall be provided to allow a visual indication of storage pressure without powering up the MMU.

3.1.4 Electrical Subsystem - The electrical subsystem shall provide the power source, power conditioning, power distribution, switching, lights, instrumentation, and data processing and transmission as required for MMU operation and checkout. The power source will be provided as GFP. Figure 8 is a block diagram of the electrical subsystem.

3.1.4.1 Power Source - The MMU shall be powered by two batteries identical to the EMU batteries as defined in Hamilton Standard Specification and Assembly Drawing SV767789. The batteries shall be easily installed or removed during EVA by an unassisted crewmember. The following information from the battery S/AD is provided for reference only:

a. Type - Silver zinc

b. Volume envelope - 3.0" x 5.0" x 10.0"

c. Weight - 9.1 lbs

d. Rated voltage - 16.8 $\pm$ 0.8 volts

e. Capacity - 400 watt hours minimum

f. Recharge time - 16 hours maximum

g. Cycle life - 12 charge/discharge cycles minimum

h. Wet stand life - 90 days minimum

3.1.4.2 Ancillary Power Outlets - Two power outlets shall be provided by the MMU for the operation of ancillary equipment. The outlets shall provide 28.0 $\pm$ 2.0 volts and be current-limited to 2.0 amps maximum.

3.1.4.3 Locator Lights - Two strobe lights shall be provided on the MMU to aid in visual location of the MMU.

3.1.4.4 Work Area Lights - Two lights shall be provided on the MMU for general illumination of the crewmember's work area (arm reach envelope).

3.1.4.5 Power Control - The following switches shall be provided for crewmember control of MMU power.

a. Main Power - two switches (one switch for bus "A" and one for bus "B").

b. Rate Gyro Power - one three-position switch (to derive gyro power from either bus "A" or bus "B").

c. Ancillary Power - two switches (one switch for bus "A" and one for bus "B").

d. Strobe Light Power - one switch for turning on/off the strobe lights.

e. Work Area Light Power - one switch for turning on/off the work area lights.

3.1.4.6 Instrumentation - The MMU shall contain the transducers and signal conditioning necessary to monitor key safety and performance parameters. As a minimum, the parameters listed in Table I shall be monitored.

3.1.4.7 Data Processing and Transmission - The instrumentation signals shall be processed and transmitted in a serial digital format to the EMU for display. An optical data link between the MMU and the EMU shall be provided to minimize donning/doffing operations, enhance crew safety, and minimize electrical interface requirements. The MMU shall interface with the EMU optical connector specified in SVHS7877. EMU data interface requirements are specified in ICD-HSD-4-0001-0D-0.

3.1.5 Mechanical Subsystem

3.1.5.1 Structure - The structure shall consist of a lightweight frame for mounting MMU components and a skin/cover layer for thermal protection. The structure shall provide sufficient rigidity to maintain component alignment and to withstand orbiter vibration, acoustic, and emergency landing loads. EMU/MMU dimensional tolerances are specified in ICD-HSD-4-0001-0D-0. The structure shall allow for rigid attachment of the MMU to the FSS in the cargo bay and the MMU to the EMU during EVA.

3.1.5.2 Mechanisms - Two independent, manually actuated latches shall be provided on the MMU for rapid donning and doffing of the EMU during EVA. Release of either latch shall allow doffing of the MMU (fail-safe). The latch receptacle on the EMU is defined in ICD-HSD-4-0001-0D-0.

3.1.6 Flight Support Station - The FSS (flight support station) shall consist of a lightweight structure with the necessary provisions for MMU stowage, donning, doffing, and servicing. The FSS shall be located in the orbiter cargo bay as shown in Figure 2. No tools or special lighting shall be required for FSS use.

3.1.6.1 Stowage - The FSS shall provide for storage and environmental protection of the MMU for launch, on-orbit, reentry, and landing.

3.1.6.2 Don/Doff - The FSS shall include the necessary attachment provisions, foot restraints, and handholds to allow one EVA crewmember, unassisted, to rapidly unstow and donn the MMU, egress and ingress the FSS, dock and doff the MMU, and restow the MMU. The latching and actuation mechanisms shall be located on the FSS and shall allow operation by the crewmember with the MMU donned. The mechanisms shall also withstand the orbiter vibration, acoustic, and emergency landing loads.

3.1.6.3 Servicing - The FSS shall contain the necessary pressure lines, gauges, and valving to accommodate MMU pressure vessel recharge.

3.2 Physical Requirements

3.2.1 External Configuration - The MMU and FSS shall be designed to accommodate all crewmember sizes accommodated by the EMU (5th percentile per AMRL-TR-70-5 to 95th percentile per WADC-TR-52-321, extrapolated to 1980). The MMU and FSS overall sizes shall be minimized and the configuration shall be contained within the maximum envelopes shown in Figures 9 and 10. The MMU configuration shall allow its transfer through the orbiter side and airlock hatches by two EVA crewmembers. Hatch opening dimensions are shown in Figure 11.

3.2.2 Weight

3.2.2.1 MMU - The MMU weight shall not exceed 225 pounds with the pressure vessels charged to 3000 psia at 70^{o}F.

3.2.2.2 FSS - The FSS weight shall not exceed 55 pounds.

3.2.3 Mass Properties - The crewmember/EMU/MMU light and heavy mass property limits shall be as shown in Table II for the determination of maneuvering acceleration response.

3.3 Flight Operational Requirements

3.3.1 General

a. The MMU shall be capable of supporting EVA operations during all on-orbit mission phases (day or night).

b. The MMU shall be capable of operating without tether attachment to the orbiter.

c. The MMU shall not preclude the attachment or removal of a safety tether to the EMU while the MMU is donned.

d. The MMU shall allow attachment of the personnel rescue system to support crew rescue.

e. The MMU shall allow installation of general purpose attachment devices to support work site activity or crew rescue.

f. The MMU shall be capable of being powered down during an EVA and restarted within 20 seconds.

g. The MMU shall not restrict EMU shoulder mobility while the MMU is donned.

h. The MMU and FSS designs shall emphasize ease of handling and minimum number of crew operations to minimize fatigue and time. All controls and mechanisms shall be easily operated by a crew member wearing a pressurized EVA glove.

3.3.2 <u>Donning and Doffing</u> - The MMU/FSS shall allow an unassisted EVA crewmember to:

a. Unstow, don, checkout, and fly the MMU out of the FSS (egress) in less than 20 minutes;

b. Dock, doff, and stow the MMU in less than 15 minutes;

c. Recharge the pressure vessels in less than 5 minutes dedicated crew time;

d. Remove and replace both MMU batteries in less than 5 minutes; and

e. Doff the MMU in less than 30 seconds in case of an emergency.

3.3.3 <u>Displays and Caution/Warning</u> - The EMU will display and limit sense the following MMU flight parameters. An audible tone will be generated by the EMU whenever MMU thrusters are fired and a different tone will be generated whenever EMU or MMU parameters become out-of-limit. Limit sense levels will be field selectable.

a. Percent propellant quantity remaining in each pressure vessel will be displayed continuously. Two limit sense levels will be provided.

b. Propellant pressure in each pressure vessel will be displayed on request. A significant difference in pressure between the two tanks will activate the warning tone and interrupt other displays to display both tank pressures.

c. Percent ampere-hours remaining in each battery will be displayed on request. If the capacity of either battery reaches a low level limit, the warning tone will be activated and other displays interrupted to display percent ampere-hours remaining.

d. Voltage of each battery will be displayed on request. If the voltage of either battery reaches a low level limit, the warning tone will be activated and other displays interrupted to display voltage.

3.4 Operability Requirements

3.4.1 Useful Life - The MMU flight hardware shall meet the requirements of this specification over a period of 15 years including operating life and storage life. A maintenance program shall be in effect during this period of useful life which will allow replacement of limited life items, repair, refurbishment, and retest. However, the design and construction of the MMU flight hardware shall minimize the degree of maintenance and servicing activities required.

3.4.1.1 Operating Life - Operating life includes all operation of the hardware during flight, or training, ground test, and pre-launch operations. The MMU flight hardware shall be designed for an operating life of 800 hours which includes 600 hours of on-orbit operation.

3.4.1.2 Storage Life - Storage life includes ground storage and handling, transportation, pre and post-launch storage in the orbiter, and on-orbit storage in the orbiter. The MMU flight hardware shall be designed for a storage life of 15 years which includes 15,000 hours of on-orbit storage.

3.4.1.3 Control of Limited Life Items - Limited life items are assemblies, sub-assemblies, and components of the MMU flight hardware that deteriorate with the passage of time or the accumulation of operating time/cycles. A limited life item requires periodic replacement, refurbishment, retesting, or operation to assure that its operating characteristics have not degraded beyond acceptable limits including consideration for total mission time/cycles and safety factor margins. Limited life items shall be subject to the following controls:

a. Each limited life item shall be clearly and indelibly marked with a serial number.

b. Appropriate documentation shall accompany all limited-life items and shall include the date of manufacture of the item and of its most time-critical component. Realistic life-limits shall be assigned and documented for each item and shall be suitably altered as new data and new evidence is obtained.

c. Status records shall be maintained on all such items and operating-time logs shall be maintained for all items having limited operating lives.

d. Special storage requirements shall be carefully defined and strictly observed.

3.4.2 Reliability - The system design shall be such that no single credible failure of the MMU or FSS shall endanger the life or safety of the crewmember during any normal or emergency operating mode. See paragraph 3.1.1.8. Attachment mechanisms or tethers required to interface the MMU with the EMU shall be fail safe. No failure of the EMU interface hardware items shall preclude the ability of the EVA crewmember, unassisted, to doff the MMU.

3.4.3 Maintainability

a. The MMU and FSS shall be designed to provide accessibility, replaceability, and serviceability consistent with efficient servicing, testing, and maintenance requirements. The use of special tools shall be minimized for normal maintenance. MMU and FSS maintenance and checkout requirements shall be compatible with a two week turnaround capability of the orbiter launches.

b. Equipment expected to require servicing, replacement, or maintenance shall be designed to be accessible without the removal of other equipment, wire bundles, and fluid lines. The CEA shall be located so that the cover can be removed and individual circuit boards removed and replaced without removing the CEA from the MMU.

c. Electrical connectors and cable installations shall be designed with sufficient flexibility, length, and protection to permit disconnection and reconnection without damage to wiring or connectors.

d. Electrical and fluid systems shall include test points which will permit planned tests to be made without disconnecting tubing or electrical connectors which are normally connected for flight.

e. Test equipment shall be designed so that failure within the equipment or interruption of power will not cause failure or damage to hardware being tested, and failure of the hardware being tested will not cause failure or damage to the test equipment or ground support equipment.

3.4.4 Environments

3.4.4.1 Ground Storage, Transportation, and Handling - The MMU shall perform as specified herein after exposure in a nonoperating (packaged unless otherwise specified) condition to the following environments.

3.4.4.1.1 Temperature - $-65^{\circ}F$ to $+150^{\circ}F$.

3.4.4.1.2 Pressure - 3 to 16 psia.

3.4.4.1.3 Humidity - 0 to 100% R.H., as defined in MIL-STD-810, Method 507.1, Procedure IV.

3.4.4.1.4 Salt Fog - 1% NaCl by weight, as defined in MIL-STD-810, Method 501.1, Procedure I.

3.4.4.1.5 Fungus - As defined in MIL-STD-810, Method 508, Procedure I.

3.4.4.1.6 Ozone - 100 parts per hundred million.

3.4.4.1.7 Thermal Radiation - 378 BTU/ft^2/hr, as defined in MIL-STD-810, Method 505.

3.4.4.1.8 Sand and Dust - 0.003 to 0.04 inches at 33 ft/sec.

3.4.4.1.9 Sinusoidal Vibration Testing - As defined in FED-STD-101, Method 5020.

3.4.4.1.10 Acceleration - $\pm$2.7g, three axes.

3.4.4.1.11 Shock - As defined in FED-STD-101, Method 5019.

3.4.4.2 Ground Test and Operations - The MMU shall perform as specified herein during or after exposure to the following environments.

3.4.4.2.1 Temperature - As shown in Figure 12.

3.4.4.2.2 Pressure - 12 to 16 psia.

3.4.4.2.3 Humidity - 8 to 100% R.H., non-operating; 22% R.H. max. at 80°F dry bulb, operating; 85% R.H. max. at 65°F dry bulb, operating.

3.4.4.2.4 Salt Fog - 1% NaCl by weight.

3.4.4.2.5 Fungus - As defined in MIL-STD-810, Method 508, Procedure I.

3.4.4.2.6 Ozone - 60 parts per hundred million.

3.4.4.2.7 Sand and Dust - 0.003 to 0.04 inches at 33 ft/sec.

3.4.4.2.8 Random Vibration - As shown in Figure 13.

3.4.4.2.9 Acceleration - $\pm$2.7g, three axes.

3.4.4.2.10 Shock - Bench handling, as defined in MIL-STD-810, Method 516.2, Procedure V.

3.4.4.3 Launch, Boost, Reentry, and Landing - The MMU shall perform as specified herein after exposure to the following environments.

3.4.4.3.1 Temperature - $-40^{\circ}F$ to $+150^{\circ}F$.

3.4.4.3.2 Pressure -16 psia to 1×10^{-10} torr.

3.4.4.3.3 Ozone - 60 parts per hundred million.

3.4.4.3.4 Random Vibration - As shown in Figure 14.

3.4.4.3.5 Sinusoidal Vibration Testing - $\pm 0.25g$ peak from 5 to 35 Hz, 3 axes, one octave per minute.

3.4.4.3.6 Acoustics - As shown in Figure 15.

3.4.4.3.7 Acceleration - $\pm 5g$, three axes.

3.4.4.3.8 Shock - $\pm 20g$ terminal peak sawtooth, 11 milliseconds, as per MIL-STD-810, Method 516, Procedure I.

3.4.4.4 Orbital Storage - The MMU shall perform as specified herein after exposure to the following environments.

3.4.4.4.1 Thermal Radiation

Solar Radiation	444 $BTU/ft^2/hr$
Earth Albedo	30%
Earth Radiation	77 $BTU/ft^2/hr$
Space Sink Temperature	0° Rankine

3.4.4.4.2 Pressure - 1×10^{-10} torr.

3.4.4.4.3 Acceleration - $\pm 5g$, three axes.

3.4.4.5 Orbital Operation - The MMU shall perform as specified herein during exposure to the following environments.

3.4.4.5.1 Thermal Radiation

Solar Radiation	444 $BTU/ft^2/hr$
Earth Albedo	30%
Earth Radiation	77 $BTU/ft^2/hr$
Space Sink Temperature	0° Rankine

3.4.4.5.2 Pressure - 1×10^{-10} torr.

3.4.4.5.3 Collision Shock - Collision with a fixed, rigid body. MMU at 2 ft/sec velocity at impact and loaded to combined mass of 20.0 slugs. Impact made with two-inch diameter semispherical end of probe extending from fixed body.

3.4.4.5.4 Nuclear Radiation - The natural nuclear radiation environment in terrestrial space consists of (a) galactic cosmic radiation (b) geomagnetically trapped radiation, and (c) solar flare particle events.

a. Galactic Cosmic Radiation (Mainly Protons)

Composition: 85% protons, 13% alpha particles, 2% heavier nuclei

Energy Range: 10^7 to 10^{19} electron volts; predominant 10^9 to 10^{13}

Flux Outside Earth's Magnetic Field: 0.2 to 0.4 particles/cm^2/steradian/sec

Integrated Yearly Rate: Approx. 1 x 10^8 protons per sq. cm

Integrated Yearly Dose: Approx. 4 to 10 rads

b. Trapped Radiation (Protons, Electrons)

Energy: Electrons > 0.5 MeV, Protons > 34 MeV

Peak Electron Flux: > 10^8 Electrons per sq. cm per sec. (omnidirectional)

Peak Electron Flux Altitude: Approximately 1,000 n.mi. at equator

Peak Proton Flux: 10^4 to 10^5 protons per sq. cm per sec (omnidirectional)

Peak Proton Flux Altitude: Approximately 1900 n.mi. at equator

c. Solar Particle Events

Composition: Energetic protons and alpha particles

Occurrence: Sporadically and lasting for several days

Particle Event Model (free space): See Section 2.4.3 of TMX 64627

$$\text{Protons: } N_p(>T) = \begin{cases} 7.25 \times 10^{11}\, T^{-1.2} & 1\text{ MeV} \leq T \leq 10\text{ MeV} \\ 3.54 \times 10^{11}\, E^{-P(T)/67} & 10\text{ MeV} \leq T \leq 30\text{ MeV} \\ 2.64 \times 10^{11}\, E^{-P(T)/73} & T \geq 30\text{ MeV} \end{cases}$$

$$\text{Alphas: } N_d(>T) = \begin{cases} N_p(>T) & T < 30\text{ MeV} \\ 7.07 \times 10^{12}\, T^{-2.14} & T \geq 30\text{ MeV} \end{cases}$$

Where Np ($>$ T), Nd ($>$ T) = protons cm^2, alphas/cm^2 with energy $>$ T

P (T) = particle magnetic rigidity in mV

$$P\ (T) = \frac{1}{Ze} \left[T \ (T + 2M\ C^2) \right]^{1/2}$$

Ze = 1 for protons, 2 for alphas

$m\ C^2$ = 938 MeV for protons, 3728 MeV for alphas

For near-earth orbital altitudes, the above free space event model must be modified since the earth's magnetic field deflects some of the low energy particles that would enter the atmosphere at low latitudes to the poles.

3.4.4.5.5 Meteoroids - The meteoroid model encompasses particles of cometary origin in the mass range between 1 and 10^{-12} grams for sporadic meteoroids and 1 to 10^{-6} grams for stream meteoroids.

Average Total Environment:

Particle Density	0.5g/cm^3
Particle Velocity	20 km/sec.
Flux Mass Models	
(1) For $10^{-6} \leq m \leq 10^0$	log Nt = -14.37 - 1.213 log m
(2) For $10^{-12} \leq m \leq 10^{-6}$	log Nt = 14.339 - 1.584 log m -0.063 $(\log m)^2$

Nt = no. particles/m^2/sec. of mass m or greater

m = mass in grams

Defocussing factor for earth, and if applicable, shielding factor are to be applied.

3.4.4.6 Reentry Crash Safety - The MMU must withstand the following g accelerations without becoming separated from the payload bay mounts.

+Aft	+Right	+Up
+9.0	+1.5	+4.5
-1.5	-1.5	-2.0

3.5 Interface Requirements

3.5.1 MMU to EMU - The MMU shall interface with the EMU as described in ICD-HSD-4-0001-OD-0.

3.5.2 FSS to Orbiter - The FSS shall be mounted to the orbiter structure in the cargo bay. When only one MMU is carried, the FSS will be mounted on the orbiter port side. When two MMUs are carried, the second FSS will be mounted on the orbiter starboard side at the same orbiter X and Z axis station. Figure 9 shows the six bolt hole locations provided by the orbiter for each FSS mounting. The FSS shall be capable of removal for missions not requiring an MMU capability. Sufficient operating envelope will be provided by the orbiter to ensure a single suited crewmember can easily don/doff the MMU. The orbiter will also provide high pressure GN_2 to the FSS location on the orbiter port side and provide connectors to mate with the FSS propellant recharge system.

3.5.3 MMU to Ancillary Equipment - The MMU shall provide electrical power outlets (paragraph 3.1.4.2) and mounting provisions for ancillary equipment such as tool carriers, photo lights, cameras, and portable workstations. The mounting provisions shall also allow attachment of MMU to worksite attachment interface equipment, tools, etc. A ring shall be provided on each side for attachment of equipment tethers.

3.5.4 MMU to Ground Support Equipment - The MMU shall be compatible with GSE (ground support equipment) during manufacture, acceptance testing, ground servicing, and maintenance. The MMU shall include a separate electrical connector for interfacing with the contractor-furnished GSE. This connector shall allow input stimuli and monitoring of output response in support of end-to-end MMU checkout.

3.6 Design Requirements

3.6.1 Manned Spacecraft Criteria and Standards - Applicable standards from JSCM 8080 have been interpreted and incorporated into this specification as cross-referenced in Table III.

3.6.2 Structure Design

3.6.2.1 Safety Factor - Ultimate - The MMU and FSS structure shall be designed to withstand at least 1.50 times the maximum operating loads without rupture or collapse.

3.6.2.2 Structural Analysis - A structural analysis including consideration of both stresses and deformations shall be performed on each primary structural member and on each essential and significant secondary structural member. When considering the strength properties of welds or any type of structural joint, the minimum values of strength provided by qualified testing or references for the components of the joint shall be used in the structural analysis. Values for allowable mechanical properties of structural materials in their design environment; e.g., subjected to single or combined stresses, shall be taken from MIL-HDBK-5, MIL-HDBK-17, MIL-HDBK-23, or other sources approved by NASA. Where values for mechanical properties of new materials or joints or existing materials or joints in new environment are not available, they shall be determined by analytical or test method approved by NASA. Complete documentation of testing and analysis used to establish material properties and design allowables shall be maintained by the contractor, and the documentation shall be made available to the procuring agency on request. When using MIL-HDBK-5, material "A" allowable values shall be used in all applications where failure of a single load path would result in loss of structural integrity. Material "B" allowable values may be used in redundant structure in which the failure of a component would result in a safe redistribution of applied loads to other load-carrying members.

3.6.2.3 Glass Structure - The design of all glass structures shall include evaluation of flaw growth under the design stress and environment. A fracture mechanics analysis shall be performed for each configuration of glass structure. A proof acceptance test consistent with the type of loading shall be conducted to screen flaws in each glass structural flight item based on the results of the fracture mechanics analysis. All proof testing shall be performed in a suitable environment to limit flaw growth during the proof testing.

3.6.3 Propulsion Design

3.6.3.1 Pressure Vessel

3.6.3.1.1 Safety Factor - Pressure vessels shall be designed to withstand a proof pressure of at least 1.5 times the maximum operating pressure and a burst pressure of 2.0 times the maximum operating pressure.

3.6.3.1.2 Negative Pressure - The pressure vessel shall not be susceptible to damage by negative pressure up to 15 psi.

3.6.3.1.3 Pressure Relief - The pressure vessel shall require pressure relief capability if the MMU design allows the pressure vessel temperature rise while in the payload bay or during EVA flight to cause the maximum safe operating pressure to be exceeded. If pressure relief is incorporated, consideration shall be given to the effects of forces applied to the MMU by actuation of the relief device.

3.6.3.1.4 Nondestructive Evaluation Plan - Nondestructive evaluation plans shall be developed during the design phase to delineate the methods and techniques used to evaluate the surface and subsurface conditions of the pressure vessel during the following phases:

a. Manufacturing;

b. Buildup and assembly;

c. Subsequent to proof testing;

d. Operational life.

3.6.3.2 Pressurized Lines, Fittings, and Components

3.6.3.2.1 Safety Factors - All pressure system components except the pressure vessel and metallic lines and fittings less than 1.5 inches in diameter shall be designed to withstand a proof pressure equal to at least 1.5 times the maximum operating pressure and an ultimate pressure equal to 2.0 times the maximum operating pressure. Metallic lines and fittings less than 1.5 inches in diameter shall be designed to withstand an ultimate pressure of 4.0 times the maximum operating pressure. Maximum operating pressure is the maximum pressure the system can be subjected to including any single failure (e.g., isolation valve leakage, regulator failure).

3.6.3.2.2 Stainless Steel Tubing--Method of Joining - Stainless steel tubing and fittings such as Ls, Ts, and couplings shall be joined by brazing or welding, except where mechanical disconnects are required for replacement or servicing, or where components would be adversely affected by brazing or welding.

3.6.3.2.3 Threaded Connectors and Sleeves--Stress Corrosion - Threaded metallic connectors and sleeves for fluid lines shall be of a material which is resistant to stress corrosion cracks when torqued to required levels and exposed to salt-air ambients typical of seacoast atmosphere. Certification tests, consisting of exposure of representative samples of flight configuration assemblies to salt air, shall be required to verify stress corrosion resistance.

3.6.3.2.4 Routing and Installation - Routing and installation of all fluid lines including pressure-sensor lines shall be specified in detail. Special precautions shall be taken to prevent the installation of such lines where they would be exposed to extreme temperature conditions. An adequate design analysis shall be made for each such line installation to show that the temperature extremes to which the line will be subjected are within limits acceptable for the fluid involved.

3.6.3.2.5 Fluid Venting - Any venting of fluids from the MMU (such as pressure relief valve) shall be accomplished in a nonpropulsive manner.

3.6.4 Electrical/Electronic Design

3.6.4.1 Electromagnetic Interference - The MMU shall perform as specified when operating either independently or in conjunction with other equipment with which there are electrical connections, or which may be installed nearby, and shall not, in itself, be a source of interference which might adversely affect the operation of other equipments. The MMU shall be designed to meet the requirements of SL-E-0002, MIL-STD-462, and MIL-STD-463.

3.6.4.2 Power Transients

a. Electrical and electronic equipment and circuits shall be designed and tested to ensure a compatible power bus transient environment. This shall include:

1) Specifying the bus transient environment

2) Limiting the transient generation characteristics of equipment to specified levels in both amplitude and time duration.

3) Assuring that the equipment is not susceptible to transients of the specified amplitude and time duration with a specified margin of safety.

b. System tests shall be performed to demonstrate that power bus transients are within specified amplitude and time duration constraints during the worst cases of loading, switching, and power source impedence.

c. Ground equipment connected to an MMU power bus shall also comply with the above requirements.

3.6.4.3 Power Distribution Circuits - Overload Protection - Maximum operating temperatures for electrical power distribution circuit elements shall be established, and overload protection devices shall be designed, selected, and calibrated to protect all elements of the circuit. The protection provided shall include considerations of wire and wire bundle derating factors that are necessary due to area environmental conditions. Protection devices for branch circuits shall be designed so that the combination of current and time required to isolate the overloaded branch circuit will not be sufficient to allow upstream protection devices to act and remove power from other branches of the power system. Where circuit changes, such as the addition of splices or wiring, are made or the environmental conditions surrounding the electrical system are changed in a manner that could adversely affect the power distribution system elements, the overload protection requirements shall be reevaluated to determine the adequacy of the protection provided.

3.6.4.4 Protection from Improper Inputs - Electrical and electronic devices shall incorporate protection against reverse polarity and/or other improper electrical inputs during certification, acceptance, and checkout tests, if such inputs could damage the devices in a way that would not be immediately and unmistakably apparent. If it is impractical to incorporate adequate protection as a part of the MMU; protection shall be provided externally by ground-based equipment at the interface between the device and the ground test equipment.

3.6.4.5 Switch Coverguards - Switches requiring coverguards shall have the coverguard designed so that the position of the switch can be determined without moving the coverguard.

3.6.4.6 Electrical Connectors Design

3.6.4.6.1 Pin Assignments - Electrical circuits shall not be routed through adjacent pins of an electrical connector if a short circuit between them would constitute a single failure that would impair crew safety.

3.6.4.6.2 Hot Connectors - Equipment shall be designed so the "hot" (live connector) end shall be the female half of the connector.

3.6.5 Redundancy

3.6.5.1 Separation of Redundant Items - Electric wiring of redundant subsystems shall not be routed in the same bundle or through the same connector. Redundant subsystem components and associated interconnecting wiring and fluid lines shall be separated by the maximum practical distance or otherwise protected to ensure that an unexpected event damaging one is not likely to prevent the other from performing the function.

3.6.5.2 Redundant Paths - Verification of Operation - The design of flight hardware systems incorporating redundancies shall include a means of verifying satisfactory operation of each redundant path during ground test and checkout.

3.6.6 Mechanical Locks - All adjustments for calibration shall have adequate mechanical locks to prevent change in MMU or component performance.

3.6.7 Human Factors - Human factors design shall be in accordance with MIL-STD-1472 and the following requirements.

3.6.7.1 Crew Operated Controls - Crew operated controls shall meet the requirements of SC-C-0005.

3.6.7.2 Mechanical and Electrical Connections - All electrical and mechanical connectors shall be keyed and/or color coded or alignment marked to preclude the possibility of incorrect connection. MMU connections that must be made and broken in flight must not exceed 10 pounds force.

3.6.7.3 EVA Support Equipment - Mobility handholds, foot restraints, and tether hooks shall meet the requirements of SC-E-0006.

3.6.7.4 Measurement Systems - Indication of Failure - Where possible, while retaining suitable accuracy and reliability of the system, those measurement systems which display critical information to the crew shall be designed so a failure of the measurement system results in the indicator deflection that will be most helpful in establishing that the measurement system has failed. This requirement is not mandatory where measurement system failures can be verified by a redundant system or other measurements.

3.6.7.5 Restriction on Detachable Crew-Operated Tools - Actuating devices shall be made an integral part of the equipment to be operated. Detachable actuating tools such as handles, pins, and ratchets shall not be permitted.

3.6.7.6 Verification of Adequate External Visibility - Visibility verification for EVA operation shall include tests, simulations, or analyses to verify the crew will have adequate visibility during all anticipated phases and environmental conditions of the planned mission. Simulations shall include mockups, as necessary, to assure the view (picture) seen by the crew during each phase of the simulated mission will be comparable to that which will be seen in flight.

3.6.8 Selection of Specifications and Standards - Specifications and standards necessary for the design and development of the MMU and FSS, in addition to those specified in this document, shall be selected in the following order of preference, except as otherwise specified in this document:

a. Manned spacecraft criteria and standards;

b. NASA specifications and standards;

c. Federal specifications and standards;

d. Military specifications and standards;

e. Other governmental specifications;

f. Specifications released by nationally recognized associations, committees, and technical societies;

g. Contractor specifications and standards;

h. Subcontractor and/or vendor specifications and standards.

3.7 Construction Requirements

3.7.1 Materials and Processes - Processes for metallic and nonmetallic materials and the selection of metallic materials shall be as specified in SE-R-0006, Section 3. Nonmetallic materials selection shall be made from JSC-07572. Nonmetallic materials not included in JSC-07572 shall require the submittal of samples to NASA for test and approval.

In addition, the following requirements shall apply.

3.7.1.1 Wire Insulation - No materials shall be used for wire insulation, ties, identification marks, and protective covering on wiring which will generate toxic fumes in a concentration sufficient to impair crew safety when exposed to a short circuit resulting in the melting of a single wire at a single point of highest resistance.

3.7.1.2 Beryllium - Restricted Use - Unalloyed beryllium shall not be used unless suitably protected to prevent erosion or formation of salts or oxides. Environmental tests under expected conditions shall be conducted to verify that the coating used provides satisfactory protection for the beryllium surface.

3.7.1.3 Cadmium - Prohibited Use - Cadmium and cadmium plating shall not be used.

3.7.1.4 Mercury - Prohibited Use - The use of equipment containing mercury in liquid or vapor form (such as manometers, lights, thermometers, etc) is prohibited where the mercury could come in contact with MMU or FSS hardware.

3.7.1.5 Polyvinyl Chloride - Prohibited Use - Polyvinyl chloride (PVC) shall not be used.

3.7.1.6 Radioactive Material - Prohibited Use - Radioactive materials shall not be used.

3.7.1.7 Metal Couples - Restriction on Use - The risk of galvanic corrosion shall be minimized by consideration of relative electrical potential (EMF) in the selection and application of metals. Metals that differ in potential by more than 0.25 volt, determined from Table IV, shall not be used in direct contact when exposed to a common electrolyte such as the atmosphere. Metal couples prohibited by or not included in Table IV shall not be used until they have been demonstrated to be satisfactory in the proposed application.

3.7.1.8 Finish Protection and Corrosion Prevention - All materials used in the MMU and FSS shall be treated to resist corrosion if not inherently corrosion-resistant, or unless the finished product will be located in a manner that it will be protected by noncorrosive lubrication film. No finishes, paints, or color markings other than those specified shall be applied to the system components--either externally or internally. All surface coatings or mating surfaces should be electrically conductive, if practicable, to prevent static charge accumulation. Use of alodine shall be in accordance with MIL-C-5541, and use of anodize shall be in accordance with MIL-A-8625.

3.7.1.9 Restriction on Coatings - Surfaces which are expected to be exposed to extensive or continuous abrasion and rubbing contact by the spacecraft crew shall not be painted or coated with other materials which are subject to flaking.

3.7.1.10 Shatterable Material - Material which can shatter shall not be used unless positive protection is provided to prevent fragments from being released.

3.7.1.11 Moisture and Fungus Resistance - The MMU and FSS shall comply with the requirements of MIL-STD-810. Materials which are not nutrients for fungus shall be used whenever possible. Fungus nutrient materials may be used in hermetically sealed assemblies and other accepted and qualified uses. Other necessary fungus nutrient materials will be treated in accordance with MIL-T-152 to render the exposed surface fungus resistant. The treated surface shall be capable of passing the fungus tests of MIL-STD-810. Hygroscopic material shall not be used except in hermetically sealed assemblies.

3.7.1.12 Castings and Stressed Areas - Nonmagnetic parts subject to high stresses shall be given penetrant inspection. When magnetic parts are subject to high stresses, they shall be magnetically inspected. Castings shall be classified stress-wise and radiographically in accordance with MIL-C-6021. Degree and method of inspection shall be approved by NASA.

3.7.1.13 Repair of Sandwich-Type Structure - The following requirements shall be satisfied before repairing sandwich-type structures by repair procedures or processes other than those repair procedures or processes used in original manufacture:

a. Engineering analysis shall be performed and verified as necessary by test to assure the planned repair method will restore the structure to within acceptable design limits. This assessment shall include consideration of the following: stress, thermodynamics, electrical properties, toxicity, aerodynamics, internal and external pressures, radiation characteristics, and venting characteristics.

b. It shall be ascertained that the mechanical and chemical aspects of the repair will not degrade adjacent material and equipment.

c. Detailed instructions shall be prepared specifying items such as materials, tools, repair sequence, time versus temperature for curing, test equipment, and test procedures required to accomplish and verify the acceptance of the repair.

3.7.1.14 Surface Roughness - Surface roughness shall be defined on drawings in accordance with ANSI B46.1-1962.

3.7.1.15 Sharp Edges - All external edges and corners of parts shall be rounded or smooth to prevent injury to personnel handling the equipment. A minimum of 0.010 inch radius shall be permitted.

3.7.1.16 Threads and Thread Inserts - All straight screw threads shall be in accordance with MIL-S-7742. Thread sizes less than 10-32 for mounting purposes and 6-32 for any thread use shall not be permitted except where exclusion of such threads will compromise the design of the components. Stainless steel helical coil thread inserts, in accordance with the pertinent MS drawings, and Kelox (or equivalent) inserts shall be used where necessary. Pipe threads shall not be permitted. The threading of screws and bolts into soft metals (Rockwell B-60 or less) or into plastics shall not be allowed.

3.7.1.17 Fasteners - All bolts and screws shall be made of materials of minimum tensile strength of 60,000 psi.

3.7.1.18 Locking Devices - Roll pins and similar type retention devices shall not be used except as specifically authorized by NASA. Use of snap rings shall be avoided; however, if snap rings are used, they shall be positively retained. All locking nuts shall incorporate metallic locking devices. Locking devices which secure rotating components shall be designed to tighten due to the rotational movement. Drive screws shall not be used in the assembly of components. Fasteners shall be securely locked or safe-tied by safety wiring or other approved methods. Safety wire shall be applied in accordance with the practice outlined in MS-33540. Star washers, lock washers, and jam nuts shall not be used.

3.7.1.19 Special Processes - Identification on Drawings - Manufacturing, assembly, or installation drawings for flight hardware, experiments, and mission essential GSE shall identify on the appropriate drawings all special processes required to manufacture, assemble, and install the equipment. Process specifications shall be referenced, or the processes shall be specified in detail on the respective drawings. Acceptance and rejection criteria associated with the operation shall be contained in the specification or on the drawings.

3.7.1.20 Separate Stock for Parts and Material - Parts and materials procured or designated specifically for use in flight hardware shall be positively identified and shall be stored in controlled-access areas. Other parts and materials shall be stored in stock rooms separated from the controlled-access area to avoid mixing.

3.7.2 Electrical, Electronic, and Electromechanical (EEE) Parts Control - The contractor shall implement a system for controlling the selection, reduction in number of types, specification, application review, analyzing failures, stocking and handling methods, installation procedures, and establishing reliability requirements for EEE parts as prescribed in Appendix 6 of the contract statement of work. In addition, the following requirements shall apply.

3.7.2.1 Closure Construction - Electrical and electronic piece parts with all-welded closure construction shall be used in preference to piece parts with other types of closure construction.

3.7.2.2 Tantalum Wet Slug Capacitors - Restriction on Use

a. Tantalum wet slug capacitors shall not be used in applications where exact timing or frequency stability is required. Polarized tantalum wet slug capacitors shall not be used in applications where reverse voltage is possible.

b. Tantalum wet slug capacitors selected for spaceflight applications shall meet or exceed the requirements of MIL-C-3965. Capacitors not qualified to Military Specifications shall be procured with specifications that include requirements for traceability of critical materials and for documentation of process controls with a requirement that the information be made available to the purchaser upon request.

c. The following minimum screen and burn-in tests shall be performed in the given sequence on one hundred percent of the capacitors to be used:

   1) Initial measurement of DC leakage and capacitance for conformance to specification requirements.

   2) Temperature cycling.

   3) Random vibration with continuous monitoring of DC leakage.

   4) High and low temperature conditioning with vacuum conditioning at low temperature.

   5) External electrolyte leakage.

   6) Burn-in (life test) at rated voltage and room temperature for a minimum of 96 hours.

   7) Final measurement of DC leakage, capacitance, and dissipation factor for conformance to specification requirements.

   8) Application of lot rejection criteria to items 1 and 7.

3.7.2.3 Transistors - Restriction on Use - The use of point-contact, grown junction, or alloy junction transistors shall be avoided in electronic circuits in both flight hardware and GSE.

3.7.3 Propulsion System - Fabrication, Handling, and Testing

3.7.3.1 Pressure Vessel

3.7.3.1.1 Certification Tests - Pressure Vessels

a. The endurance of the pressure vessel under stress and in contact with each fluid to be used for flushing, inspecting, testing, or operating shall be demonstrated during a certification test program.

b. Representative pressure vessels shall be subjected to:

1) Each fluid which is expected to be contained in the flight item

2) The same sequence that these fluids are expected to be contained

3) The maximum pressure allowed by the relief device or maximum pressure expected, for pressure vessels without relief devices, when each fluid is contained

4) The maximum temperature expected for each fluid

5) Twice the expected time each fluid will be contained in the vessels during processing and testing

c. The vessel, while containing the flight fluid, shall be subjected to 25 cycles of 10 days at the above temperatures and pressures and 1 day at ambient temperature and pressure.

3.7.3.1.2 Pressure Vessel Documentation - Manufacturing, processing, and pressurization histories shall be maintained on each pressure vessel. The minimum data required is as follows:

a. Material certification and composition.

b. Actual fabrication and processing sequence.

c. Fluid exposure and temperature during fabrication and testing.

d. Actual chronological tests and checkout history including all proof, leak, and cycling data along with the magnitude of pressure, type of pressurant, and number of pressure cycles to which the tank was subjected.

e. Discrepancy history.

3.7.3.2 Pressurized Lines, Fittings, and Components

3.7.3.2.1 Radiographic Inspection of Joints - Radiographic inspection shall be used on brazed and welded tubing joints as necessary to verify that the brazing or welding process is under proper control. The use of radiographic inspection does not preclude the need for other established inspection procedures, such as visual examination, proof tests, and leak tests.

3.7.3.2.2 Protection Against Incorrect Installation - Positive measures shall be taken to prevent incorrect installation of fluid line components whose function is dependent on direction of flow.

a. Where feasible, the design of these fluid line components shall incorporate end fittings or connections whose dimensions or configuration will not permit incorrect installation.

b. The direction of fluid flow shall be clearly indicated with permanent markings on the exterior of the component and the parts and lines to be mated with it.

c. Where feasible, flow checks shall be made after each installation or change.

3.7.3.2.3 Protection Against Damage and Contamination

a. All ends of tubing, fittings, and components used in fluid systems shall be protected against damage and entry of contaminants in each step of the flight hardware assembly. Design drawings and/or process specifications shall designate the method of complying with this requirement.

b. Equivalent protection shall be provided for tubing, fittings, and/or components when the fluid system is open to effect repair or replacement.

c. Tubing assemblies, fittings, or components, which are stored or shipped, shall be protected as above and shall be sealed in a clean transparent, moisture-proof bag with sufficient protective strength and thickness. Sealing shall be done in an air-conditioned environment with 50%, or lower, relative humidity. All assemblies shall be cleaned and dried before packaging.

3.7.3.2.4 Protection of Nozzles - All nozzles and vents shall be protected from entrance of rain, debris, or other contaminants. Protective covers shall be designed to be readily removable and shall be designed so removal can be accomplished without risk of dumping accumulated debris into the nozzle or vent, or damaging nozzle radiation coatings. The covers shall be designed so failure to remove the cover shall not cause failure of the system.

3.7.3.2.5 Capping of Servicing and Test Ports - Servicing and test ports, not required to function during normal operation, shall be designed to preclude contamination by capping immediately after servicing or test.

3.7.3.2.6 Pressure Relief Valves - Standardization of Functional Test - To provide consistency in initial and subsequent testing of pressure-relief valves, the manufacturer shall specifically establish pressures and corresponding mass-flow rates for valve crack point, reseat point, specification relief pressure and allowable leakage. These values shall be specified for the flight fluid and for any other fluid recommended for test purposes. Retest time intervals shall be specified for the valves which are subject to deterioration with time.

3.7.3.3 Fluids

3.7.3.3.1 Certification Fluid - Fluids used in the successful equipment certification shall be tested and analyzed as required to establish baseline reference data on the physical and chemical properties of the fluid and allowable impurities that could affect the performance of the equipment and compatibility of materials. The effect on system and component certification shall be evaluated, and any additional certification required shall be defined before any of the following changes are allowed:

a. Change in fluid specification.

b. Change in procurement source.

c. Change in fluid processes, process conditions, or handling procedures.

d. Change in raw materials or their sources.

e. Shifts in fluid properties noted in new lots or batches whenever these properties are not specifically allowed by the procurement specification.

3.7.3.3.2 Liquid or Gas Containers - Verification of Contents - The contents of each individual liquid or gas container to be used in flushing, testing, checkout, and operation of the MMU and FSS, shall be shown, by laboratory analysis, to conform to specified requirements prior to use.

3.7.3.4 Fluid System Cleanliness - The fluid system shall be maintained in the state of cleanliness required by the specification for the working fluid after factory assembly and up to and including final servicing prior to flight. This requirement shall also apply to the gas and liquid-handling system of all servicing, maintenance, handling, test, and checkout equipment. Gases or liquids or test fluids that enter the fluid system shall be filtered and controlled such that the degree of cleanliness required by the specification for the working fluid is maintained.

3.7.3.4.1 Design for Flushing and Draining - The fluid system and related servicing equipment shall be designed to permit complete flushing and draining during ground servicing operations. The following conditions shall be satisfied as a minimum:

a. The system shall be free from dead-ended piping or passages through which flushing fluid cannot be made to flow.

b. Drain and bleed ports shall be provided for attitudes anticipated during ground servicing of the systems.

3.7.3.4.2 Flushing Requirements - After manufacturing and after any subsequent exposure to the probable entry of contaminants, all fluid system and servicing equipment shall be cleaned by flushing to remove all contaminants which could be detrimental to the system. The flushing fluid shall be compatible with the system materials and the working fluid to be used in the system. Cleanliness levels of the flushing fluid and the maximum allowable contamination shall be specified. During flushing, the fluid shall be filtered to the same level of cleanliness as the working fluid to be used.

3.7.3.4.3 Verification of Draining, Purging, and Flushing Operations Whenever the fluid system or its servicing equipment is drained, purged, or flushed, samples of the fluid leaving the system shall be analyzed to determine that particulate and/or chemical contamination are within specified limits. The fluid sample shall be taken at the end of the purging or flushing operation.

3.7.3.4.4 Review of Cleaning Procedures - At the time of preparation, cleaning, flushing, and purging procedures for the fluid system shall be reviewed and tests shall be performed as required to assure compatibility between the system materials and the fluids used. The reviewer shall certify that no adverse long-term reactions will occur as a result of the residuals that may be expected to remain in the system following completion of the cleaning, flushing, and purging procedure. Certified procedures shall be submitted to NASA for review prior to use.

3.7.3.4.5 Leak Detectors - Wetting Agents - Any wetting agent to be used on the outside surface of pressurized systems to detect leaks shall be verified to be compatible with the materials on which it is to be used or materials on which it might be spilled. After the leak tests are completed, the wetting agent shall be neutralized or removed by a washing and drying procedure compatible with the materials.

3.7.4 Electrical/Electronic - Fabrication, Handling, and Testing

3.7.4.1 Electrical Wiring

3.7.4.1.1 Wire Splicing - Splicing of wire shall be avoided if possible. If splicing is absolutely necessary, the splice must be witnessed and inspected by a certified contractor or NASA representative. Records shall be kept on the splice showing operator, contractor's inspector, date, location of wire and splice, and other data deemed appropriate for complete record of the splice. Splices not incorporated on drawings shall require Material Review Board (MRB) approval.

3.7.4.1.2 Etching Wire Insulation

a. When etching of wire insulation is required to provide satisfactory bonding to potting materials, the open end of the wire shall not be exposed to the etchant. The preferred process is to form the wire into a "U" shape, immersing only the bent portion in the etchant with the open ends above the etchant level. The unetched end of the wire shall not be cut off prior to neutralization of the etchant.

b. Electrical wire or cable insulated or coated with polytetrafluoroethylene (TFE) or fluorinated ethylene proplyene (FEP) shall be etched prior to potting to assure mechanical bond strength and environmental seal.

c. Potting shall be accomplished within three weeks after etching.

3.7.4.1.3 Wire Bundles - Protective Coating - Where protective coating or sheathing is added to wire bundles, ability to withstand anticipated handling and operating deformations without wire damage shall be demonstrated by appropriate certification test programs.

3.7.4.1.4 Wire Harnesses - Dielectric Tests

a. Upon completion of fabrication but prior to permanent installation, wires and connectors of electrical wire harnesses shall be tested for shorting or dielectric failure by applying an a-c or d-c voltage equal to 75 percent of the connector's respective a-c or d-c sea level rated voltage in the following steps:

   1) Between the connector shell and all contacts connected together.

   2) Between each contact and all other contacts connected together in progression (previously checked individual contacts need not be reconnected to the group).

b. Contacts connected to wire harness wires, components, or devices not capable of withstanding the connector's sea level rated voltage shall not be subjected to the dielectric test.

c. Voltages shall be applied by increasing gradually from zero to the desired potential at a rate of increase not to exceed 500 volts per second. After three to five seconds at the desired potential, the voltage shall be decreased to zero at a rate not to exceed 500 volts per second.

d. Following permanent installation of wire harnesses, but prior to connection to components or devices, the dielectric test shall be repeated.

3.7.4.2 Electrical Connectors

3.7.4.2.1 Electrical Circuits - De-energizing Requirement - Electrical systems shall be designed so that all necessary mating and demating of connectors can be accomplished without producing electrical arcs that will damage connector pins or ignite surrounding materials or vapors. Unless connectors are specifically designed and approved for mating or demating in the existing environment under the loads being carried, they shall not be mated or demated until voltages have been removed from the powered side(s) of the connector.

3.7.4.2.2 Protective Covers or Caps - Electrical plugs and receptacles of flight equipment and ground equipment that connects with flight equipment shall be protected at all times. Protective covers or caps shall be placed over electrical plugs and receptacles whenever they are not connected to the mating part. The protective covers or caps shall:

a. Be resistant to abrasion, chipping, or flaking.

b. If permanently attached and used in flight, be of the same finish and material as the connectors to which they attach and be secured by lanyards.

c. If not used in flight, be brightly colored so as to easily disconcernable and command attention.

d. Be maintained at a level of cleanliness equivalent to the plugs or receptacles on which they are used.

e. Be made of material which is compatible with the connector material.

3.7.4.2.3 Moisture Protection - Electrical connectors and wiring junctions to connectors shall be sealed from moisture to prevent open and short circuits.

3.7.4.2.4 Materials Detrimental to Electrical Connectors - Materials containing or coated with substances known to be detrimental to metals used in electrical connectors, shall not be used adjacent to exposed electrical contact surfaces. Specifically included in this category are materials containing or coated with sulfides or free sulfur.

3.7.4.2.5 Shorting Springs or Clips - Shorting springs or shorting clips shall not be used in electrical connectors.

3.7.4.3 Electrical Equipment Handling

3.7.4.3.1 Protection from Moisture Damage - Electronic and electrical equipment which is not hermetically sealed or otherwise positively protected against moisture shall not be cooled below the dew point of the surrounding atmosphere. This requirement shall include test conditions (except for environmental certification test articles) and all operating conditions, including flight, wherein condensation of moisture can occur either during equipment operation, before equipment is brought up to operating temperature, or after equipment is shut down.

3.7.4.3.2 Ultrasonic Cleaning - Ultrasonic vibration shall not be used as a method for cleaning electronic assemblies unless it can be shown that the reliability of the components in the assembly will not be degraded by the process used.

3.7.4.3.3 Testing Protective Devices for Solid State Circuits - Protective devices used in electronic circuits to protect solid state circuits elements shall be verified as ready to function as intended after the environmental acceptance test of the circuit assembly and after any event, such as maintenance, handling mishaps, etc., which could physically damage the circuit.

3.7.4.3.4 Disconnection of Connectors for Troubleshooting and Bench Testing - Where electrical connectors of flight hardware are disconnected to provide access to circuits for troubleshooting and bench testing, the test equipment used shall be fitted with connectors that mate with the appropriate flight hardware connectors. The test equipment shall not be connected to flight hardware circuits by insertion of meter probes directly into electrical connector sockets, by holding meter probes against connector pins, or by attachment of alligator clips to connector pins. To minimize wear on spaceflight equipment connectors, jumper cables with mating connectors may be installed and remain on the flight hardware for bench tests up to the time of installation in the spacecraft.

3.7.5 Workmanship - Workmanship shall be of aerospace quality, consistent with the reliability requirements of the type of equipment, and shall conform to high grade aerospace manufacturing practices.

3.7.6 Debris Protection - Malfunction or inadvertent operation of electrical, electronic, or mechanical equipment caused by exposure to conducting or nonconducting debris or foreign material floating in a gravity free state shall be prevented by the following:

a. Electrical circuitry shall be designed and fabricated to prevent unwanted current paths being produced by such debris.

b. Critical mechanical items shall be provided with debris-proof covers or containers, while critical electrical items shall be provided with suitable containers, potting, or epoxy coating.

c. Filters, strainers or traps shall be provided in all moving-fluid systems to trap residual debris in a manner which will eliminate it as a threat to critical mechanical or electrical components. In installations wherein flow reversal may occur, filters or strainers shall be installed on both sides of critical components.

d. Threaded fittings and fasteners such as nuts, nut plates, bolts, etc. shall be designed to minimize the generation of metallic particles or foreign material. These threaded devices shall be applied in a manner to preclude the release of particles or foreign material where interference with proper operation of system components could occur.

3.7.7 Cleanliness - The internal and exterior parts of the MMU and FSS shall meet the requirements of SN-C-0005. Filters shall conform to the requirements of SE-F-0044.

3.7.8 Usage and Safety Precautions

3.7.8.1 Intermittent Malfunctions - Prohibited Use of Equipment - Equipment that exhibits or has exhibited intermittent malfunctions, failures or anomalies, shall not be used for flight until the malfunction, failure, or anomaly has been corrected or resolved.

3.7.8.2 Equipment Failure and Replacement - Equipment which has failed during pre-flight checks, and has been replaced, shall not be permitted for flight unless:

a. An analysis of the failure has established that the basic deficiency which caused the failure is not present in the replacement equipment, or

b. The basic deficiency has been counteracted by changes in operational procedures to a degree that eliminates it as a significant threat to the success of the mission and safety of the crew, or

c. The basic deficiency is determined to represent no significant threat to the success of the mission and safety of the crew.

3.7.8.3 Test and Operating Procedures - Procedures developed for testing and operating flight hardware or ground support equipment shall clearly indicate any step which, if not correctly followed, would result in serious injury to personnel.

3.7.9 Interchangeability and Replaceability Requirements - All replaceable parts or assemblies having the same part number shall be directly and completely interchangeable with each other with respect to installation and performance. Each assembly shall be designed to be replaceable with all other assemblies having the same part number without requiring the replacement of the other assemblies. Interchangeability requirements are not applicable to detail parts of permanent assemblies such as welded assemblies, or matched detailed parts such as lapped components. Interchangeability requirements do not apply to custom fitted or sized items.

3.7.10 Identification and Marking - Flight equipment and nonflight equipment (not suitable for use in flight but which could be accidentally substituted for flight articles) shall be identified as follows:

3.7.10.1 Flight Hardware - Identification and marking of the flight hardware, its subassemblies and parts with their assigned part number shall be in accordance with MIL-STD-130. Name plates shall be used for identification of the flight hardware and major subassemblies in accordance with MIL-P-6906. Marking for shipment shall be per MIL-STD-129.

3.7.10.2 Class II - Equipment Acceptable for Use in Ground Tests or Training in a Hazardous Environment -The name plate or label adjacent to the name plate shall be conspicuously marked "Class II, CONTROLLED EQUIPMENT" with flight compatible material.

3.7.10.3 Class III - Equipment Acceptable for Nonhazardous Training or Display Purposes - This equipment shall be conspicuously identified by red (or orange) stripes alternating with a contrasting base color or painted solid red. An alternative to the paint method of identification is a red (or orange) striped name plate or label marked "Class III, NOT FOR FLIGHT" applied to the equipment. The identification shall be visible when the equipment is installed.

4.0 VERIFICATION REQUIRMENTS

4.1 Product Verification - The following methods shall be used to verify that the MMU meets the requirements specified herein:

a. Inspection of hardware;

b. Analysis of drawings and data;

c. Demonstration;

d. Component, subsystem, and system tests.

4.2 Test Types

4.2.1 Acceptance Tests - Acceptance tests shall be conducted on all flight hardware end items. Acceptance testing, test procedures, data sheets, problem reporting, and corrective action shall meet the requirements of SP-T-0023B.

4.2.2 Development Tests - Development tests shall verify the feasibility of the design approach by evaluating hardware failure modes, design margins, performance under simulated or actual environmental conditions and provide confidence in the ability of hardware to pass certification tests. Hardware used for development testing shall be representative of, but not necessarily identical to, flight hardware to be presented for acceptance. This hardware shall not be used in any end item of flight hardware.

4.2.3 Certification Tests - Certification tests, combined with other verification methods of this specification, shall verify that flight hardware design meets the technical requirements of Section 3 of this specification to assure operational suitability in the anticipated environments. Certification test hardware shall be used for certification testing and shall be identical in configuration and production processing to flight hardware. Certification test methods shall meet the requirements of MIL-STD-810 or equivalent and certification testing shall be accomplished in accordance with the following general requirements:

a. Certification tests shall be conducted at the highest practical level of assembly. If tests are required at several levels, those at lower levels shall be completed prior to those at higher levels of assembly.

b. Acceptance tests shall be conducted on certification test hardware prior to certification tests being conducted.

c. Tests to determine whether the certification test hardware is performing within specification tolerances shall be conducted before and after each environmental exposure. The same tests shall be performed during the exposure period if the flight hardware will be required to operate in that environment. If the tests are conducted in series with no significant time interval between tests, the tests after an environmental exposure may serve as verification of proper performance before the succeeding environmental exposure.

d. Certification test hardware shall be mounted in a manner simulating the actual mounting in the flight vehicle for all certification tests wherein the flight hardware is expected to be affected by the mounting.

e. Certification tests shall be performed under strict control of environments and test procedures. Adjustment or tuning of certification test hardware is not permitted during tests unless it is normal to in-service operation.

f. If the design configuration or manufacturing processes are changed after acceptance tests on certification test hardware are initiated, any differences existing between the certification test hardware and the flight hardware will invalidate verification. The Contractor shall perform an analysis of the change to determine the impact of the change on the certification status and shall recommend to NASA the extent of retest required.

g. Certification tests shall be completed prior to the delivery of flight hardware.

h. Personnel performing the certification tests shall be thoroughly familiar with all assembly, acceptance test, and certification test procedures. The hardware developer shall assign a single individual as a test monitoring engineer to control all certification test operations, maintain a complete test operations log, assure that all tests are conducted properly and thoroughly as required in the applicable certification test procedure and control the certification test area.

4.3 Application of Previous Certification Tests

a. Previous certification tests conducted on items for other programs may be considered to be applicable to items proposed for the flight hardware provided:

1) There are no changes in the following:

Design and specifications including operating limits, weight, dimensions, materials, performance and tolerance, reliability, and quality.

Fabrication methods.

Inspection techniques.

Manufacturing environment and tests up to the point where certification tests would normally be initiated.

Electromagnetic interference.

2) Present items are from the same manufacturing continuous-built lot as the certified items.

b. A change in any of the above must be reported by the manufacturer. Validation is required, by an engineering analysis or identifiable test report, that the change does not adversely affect the certification of the item.

c. A certificate of compliance is required from the manufacturer confirming the items listed in the preceding paragraphs.

4.4 Verification Matrix - The individual technical requirements of Section 3 shall be verified according to the verification methods and test types as specified in Table V.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging, Handling, and Transportation - Packaging, handling, and transportation requirements shall be as specified in NHB 6000.1 (1A)

Table I MMU Instrumentation List

TITLE	TYPE	ENGINEERING UNITS	MEASUREMENT RANGE
Cue, Thruster	Bilevel	N/A	On-Off
Detector, Spin Motor Rotation	Bilevel	N/A	On-Off
Power, System A Battery	Analog	Amp-hours	0 to 30
Pressure, System A Propellant	Analog	psi	0 to 5,000
Temperature, System A Propellant	Analog	^{o}F	-200 to +200
Voltage, System A Battery	Analog	volts	0 to 20
Power, System B Battery	Analog	Amp-hours	0 to 30
Pressure, System B Propellant	Analog	psi	0 to 5,000
Temperature, System B Propellant	Analog	^{o}F	-200 to +200
Voltage, System B Battery	Analog	volts	0 to 20

Table II Crewmember/EMU/MMU Mass Properties

WEIGHT RANGE

LIGHT Limit		HEAVY Limit	
5% Man	143 lb	95% Man	215 lb
EMU (11 lb H_2O expended)	165 lb	EMU	184 lb
MMU (with 3 lb residual N_2)	205 lb	MMU (with 40 lb N_2)	242 lb
	513 lb		641 lb

COMBINED MASS PROPERTIES

Parameter	Symbol	Light Limit	Heavy Limit
Mass	M	16.0 slugs	19.9 slugs
Moments of Inertia	Ixx	27.8 slug ft^2	38.6 slug ft^2
	Iyy	29.9 slug ft^2	41.7 slug ft^2
	Izz	15.5 slug ft^2	20.2 slug ft^2
Products of Inertia	Ixy	TBD	TBD
	Ixz		
	Iyz		
Thruster Lever Arms	Lx	4.5 inches	4.5 inches
	Ly	13.4 inches	13.4 inches
	Lz	21.0 inches	21.0 inches

Table III Applicability of Manned Spacecraft Criteria and Standards (JSCM 8080)

Standard Number	Specification Paragraph	Standard Number	Specification Paragraph
1A	3.4.3.a,b,c	44	N/A
2A	N/A	45	N/A
3A	3.6.7.2	46	N/A
4B	3.6.5.1	47	3.7.3.2.5
5	3.7.2.3	48	N/A
6A	N/A	49	3.7.3.2.2
7	3.4.3.d	50A	N/A
8A	N/A	51	3.7.1.2
9	3.7.6.a,b,c	52	3.7.2.2
10	N/A	53	N/A
11A	N/A	54	N/A
12A	3.1.1.8, 3.4.2	55	N/A
13	3.6.4.4	56	N/A
14	3.6.3.2.3	57A	N/A
15	Cancelled	58	N/A
16	N/A	59	3.6.4.5
17	N/A	60	N/A
18	3.7.1.5	61	N/A
19	3.7.2.1	62	3.7.6.d
20A	3.6.5.1	63	3.7.1.7
21A	3.4.4.5.5	64	3.7.3.2.4
22A	N/A	65	3.6.7.5
23	3.7.1.1	66	N/A
24	N/A	67	N/A
25	3.7.4.1.3	68	N/A
26	N/A	69	3.7.4.2.1
27	N/A	70	N/A
28	3.7.8.1	71	N/A
29	3.6.3.2.2	72	N/A
30	N/A	73	N/A
31	3.7.4.2.3	74	N/A
32	3.6.4.6.1	75	3.6.7.4
33	N/A	76	3.6.3.2.4
34	N/A	77	3.4.1.3
35	N/A	78	3.7.3.4
36	3.6.5.2	79	*
37	N/A	80	3.7.4.3.1
38A	3.7.3.4.1	81	3.7.4.3.2
39A	N/A	82	N/A
40	Cancelled	83	4.3
41	3.7.1.10	84A	5.0
42	N/A	85A	3.7.4.2.2
43	3.7.1.9	86	*

N/A = Not Applicable

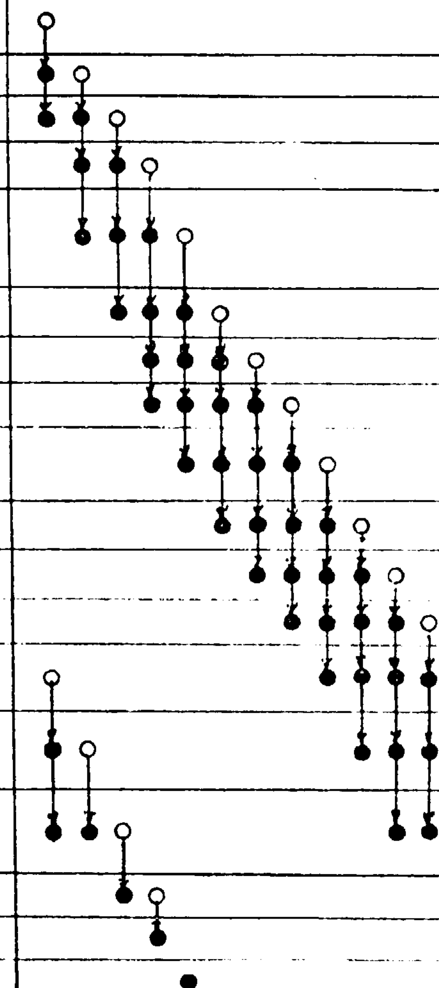
* = Applicable for procurement

Table III (cont'd)

Standard Number	Specification Paragraph	Standard Number	Specification Paragraph
87A	3.7.3.2.1	131	N/A
88A	3.7.4.1.1	132	3.6.3.1.2
89	N/A	133	3.7.4.1.4
90A	N/A	134	3.6.4.3
91	3.7.3.3.2	135	3.7.1.13
92	3.7.3.2.6	136	N/A
93	3.7.3.2.3	137	3.6.3.1.5
94	3.7.3.4.3	138	N/A
95A	N/A	139	3.6.3.1.1
96	N/A	140	3.7.3.1.2
97	3.7.3.4.2	141	3.7.1.6
98	3.7.4.1.2.a	142	3.7.1.16
99B	3.7.10	143	N/A
100	3.7.8.2	144	3.6.2.3
101	3.7.4.2.4	145	N/A
102	N/A	146	3.6.4.2
103	N/A	147	3.7.3.3.1
104	N/A	148	3.7.4.3.3
105A	N/A	149	3.6.3.1.4
106	N/A	150	N/A
107	3.7.1.20	151	N/A
108A	N/A	152	N/A
109	3.7.4.1.2.b,c		
110A	3.6.2.2		
111	3.7.3.4.5		
112	3.7.4.3.4		
113	Cancelled		
114	3.7.3.1.1		
115	3.7.8.3		
116	3.7.1.4		
117	3.7.3.4.4		
118	N/A		
119	3.7.1.19		
120	N/A		
121	N/A		
122	N/A		
123	N/A		
124	N/A		
125	3.7.1.3		
126	3.6.7.6		
127	N/A		
128	3.7.4.2.5		
129	3.7.10.1		
130	N/A		

Table IV Metal Couples

Grp. No.	Metallurgical Category	E.M.F. (Volt)	Permissible Couples *
1	Gold, solid and plated; gold-platinum alloys; wrought platinum	+0.15	
2	Rhodium, graphite	+0.05	
3	Silver, solid or plated; high silver alloys	0	
4	Nickel, solid or plated; monel metal, highnickel-copper alloys, titanium	-0.15	
5	Copper, solid or plated; low brasses or bronzes; silver seller; German silver; high copper-nickel alloys; nickel-chromium alloys; Austenitic stainless steels	-0.20	
6	Commercial yellow brasses and bronzes	-0.25	
7	High brasses and bronzes; Naval brass; Muntz metal	-0.30	
8	18% chromium type corrosion-resistant steels	-0.35	
9	Chromium, plated; tin, plated; 12% chromium type corrosion-resistant steels	-0.45	
10	Tin-plate; terneplate; tin-lead solders	-0.50	
11	Lead, solid or plated; high lead alloys	-0.55	
12	Aluminum, wrought alloys of the Duralumin type	-0.60	
13	Iron, wrought, gray, or malleable; plain carbon and low alloy steels, armco iron	-0.70	
14	Aluminum, wrought alloys other than Duralumin type; aluminum, cast alloys of the silicon type	-0.75	
15	Aluminum, cast alloys other than silicon type; cadmium, plated and chromated	-0.80	
16	Hot-dip-zinc plate; Galvanized steel	-1.05	
17	Zinc, wrought; zinc-base die-casting alloys; zinc, plated	-1.10	
18	Magnesium and magnesium-base alloys cast or wrought **	-1.60	



* Members of groups connected by lines are considered to form permissible couples. These permissible couples should not be construed to be totally devoid of galvanic action, but rather to represent an acceptably low galvanic effect. O Indicates the most cathodic member of the series, ● an anodic member, and the arrows the anodic direction.

** Aluminum alloys 5052, 5056, 5356, 6061, and 6063 are considered to form permissible couples with magnesium alloys.

Table V Verification Matrix

Verification Method	Test Type
1. Inspection of Hardware	A. Component/Subsystem Acceptance Test
2. Analysis of Drawings and Data	B. Component/Subsystem Development Test
3. Demonstration	C. Component/Subsystem Certification Test
	D. System Acceptance Test
	E. System Development Test
	F. System Certification Test

Technical Requirement		Verif. Method			Test Type					
		1	2	3	A	B	C	D	E	F
3.1.1	General Requirements		X							
3.1.2.1	Reference Coordinate System		X							
3.1.2.2	Hand Controllers				X	X		X		
3.1.2.3	Control Authority		X					X		
3.1.2.4	Automatic Attitude Hold		X							
3.1.2.5	Cross-Axis Effects		X							
3.1.3.1	Propellant Storage		X							
3.1.3.2	Pressure Regulation				X			X		
3.1.3.3	Thruster Response		X		X					
3.1.3.4	Propellant Isolation Valve							X		
3.1.3.5	Charging Quick Disconnect			X				X		
3.1.3.6	Toggle Valve							X		
3.1.3.7	Pressure Gage							X		
3.1.4	Electrical Subsystem				X					
3.1.5	Mechanical Subsystem			X	X					
3.1.6	Flight Support Station		X	X						
3.2.1	Configuration		X	X						
3.2.2	Weight			X						
3.2.3	Mass Properties		X							
3.3	Flight Operational Requirements			X				X		
3.4.1	Useful Life		X							
3.4.2	Reliability		X							
3.4.3	Maintainability		X	X						
3.4.4.1.1	Temperature								X	X
3.4.4.1.2	Pressure								X	X
3.4.4.1.3	Humidity		X							
3.4.4.1.4	Salt Fog		X							
3.4.4.1.5	Fungus		X							
3.4.4.1.6	Ozone		X							
3.4.4.1.7	Thermal Radiation		X							
3.4.4.1.8	Sand and Dust		X							
3.4.4.1.9	Sinusoidal Vibration Testing								X	X
3.4.4.1.10	Acceleration		X							
3.4.4.1.11	Shock								X	X
3.4.4.2.1	Temperature	X						X		
3.4.4.2.2	Pressure								X	X
3.4.4.2.3	Humidity								X	X
3.4.4.2.4	Salt Fog								X	X
3.4.4.2.5	Fungus		X							

Table V Continued

Technical Requirement		Verif. Method 1	Verif. Method 2	Verif. Method 3	Test Type A	Test Type B	Test Type C	Test Type D	Test Type E	Test Type F
3.4.4.2.6	Ozone		X							
3.4.4.2.7	Sand and Dust								X	X
3.4.4.2.8	Random Vibration	X						X		
3.4.4.2.9	Acceleration		X							
3.4.4.2.10	Shock								X	X
3.4.4.3.1	Temperature								X	X
3.4.4.3.2	Pressure								X	X
3.4.4.3.3	Ozone		X							
3.4.4.3.4	Random Vibration								X	X
3.4.4.3.5	Sinusoidal Vibration Testing								X	X
3.4.4.3.6	Acoustics		X							
3.4.4.3.7	Acceleration		X							
3.4.4.3.8	Shock								X	X
3.4.4.4.1	Thermal Radiation								X	X
3.4.4.4.2	Pressure								X	X
3.4.4.4.3	Acceleration		X							
3.4.4.5.1	Thermal Radiation								X	X
3.4.4.5.2	Pressure								X	X
3.4.4.5.3	Collision Shock								X	X
3.4.4.5.4	Nuclear Radiation		X							
3.4.4.5.5	Meteoroids		X							
3.4.4.6	Re-Entry Crash Safety								X	X
3.5	Interface Requirements			X				X		
3.6.2	Structure Design		X							
3.6.3.1.1	Safety Factor - Pressure Vessel				X	X	X			
3.6.3.1.2	Negative Pressure					X				
3.6.3.1.3	Flow Restriction				X					
3.6.3.1.4	Non-Destructive Evaluation Plan		X							
3.6.3.2.1	Safety Factor-Pressurized Lines, Fittings & Components				X	X	X	X	X	X
3.6.3.2.2	Stainless Steel Tubing-Method of Joining	X								
3.6.3.2.3	Threaded Connectors and Sleeves - Stress Corrosion					X	X			
3.6.3.2.4	Routing and Installation		X							
3.6.4.1	Electromagnetic Interference								X	X
3.6.4.2	Power Transient								X	X
3.6.4.3	Power Distribution Circuits - Overload Protection		X							
3.6.4.4	Protection from Improper Inputs		X							
3.6.4.5	Switch Coverguards			X						
3.6.4.6	Electrical Connectors Design	X	X							
3.6.5.1	Separation of Redundant Items		X							
3.6.5.2	Redundant Paths-Verification of Operation							X		
3.6.6	Mechanical Locks	X	X							
3.6.7	Human Factors Design		X	X						
3.6.8	Selection of Specifications and Standards		X							

Table V Continued

Technical Requirement		Verif. Method 1	2	3	Test Type A	B	C	D	E	F
3.7.1	Materials and Processes Control	X	X							
3.7.2	EEE Parts Control	X	X							
3.7.3.1.1	Certification Test-Pressure Vessel					X	X			
3.7.3.1.2	Pressure Vessel Documentation		X							
3.7.3.2	Pressurized Lines, Fittings, & Components	X	X							
3.7.3.3	Fluids	X	X							
3.7.4.1.1	Wire Splicing	X								
3.7.4.1.2	Etching Wire Insulation	X								
3.7.4.1.3	Wire Bundles-Protective Coating								X	X
3.7.4.1.4	Wire Harnesses - Dielectric Tests				X					
3.7.4.2	Electrical Connectors	X	X							
3.7.4.3	Electrical Equipment Handling	X	X							
3.7.5	Workmanship	X								
3.7.6	Debris Protection	X	X							
3.7.7	Cleanliness	X								
3.7.8	Usage and Safety Precautions		X							
3.7.9	Interchangeability and Re-placeability		X							
3.7.10	Identification and Marking	X								

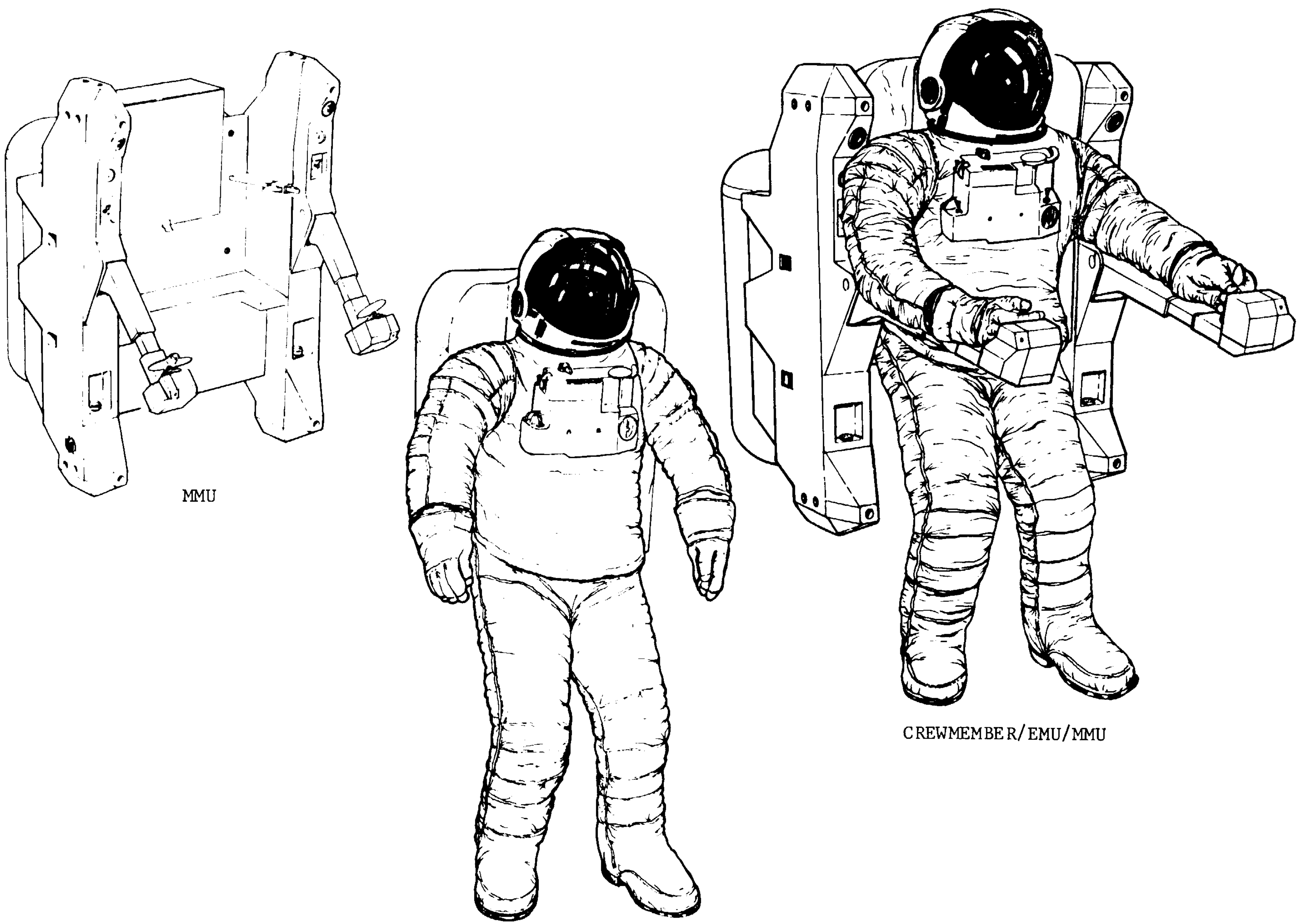
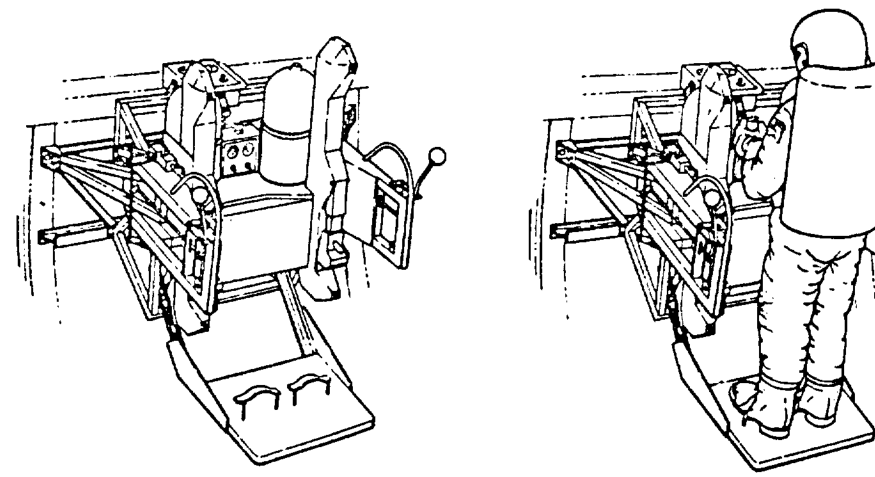
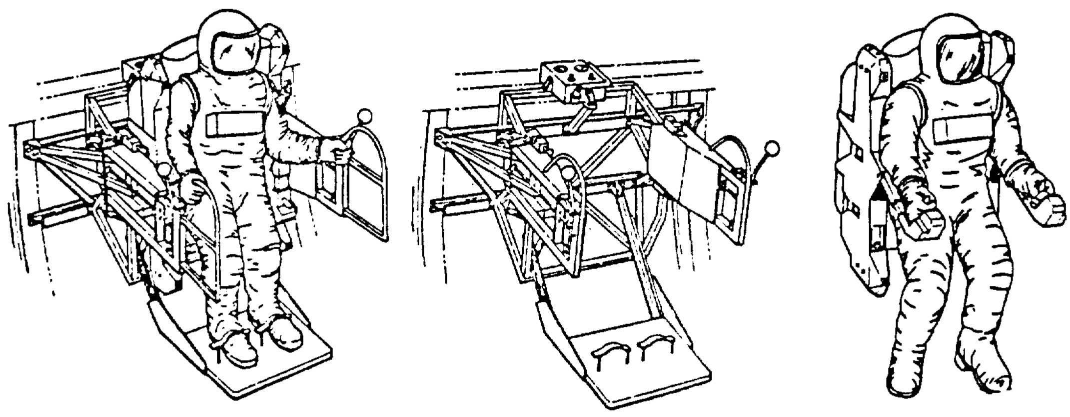


FIGURE 1 SHUTTLE MMU CONFIGURATION



LAUNCH, ENTRY AND ON-ORBIT STOWAGE

SERVICING (PROPELLANT CHARGE)



DONNING CONFIGURATION

EGRESS/INGRESS

FIGURE 2

MMU FLIGHT SUPPORT STATION

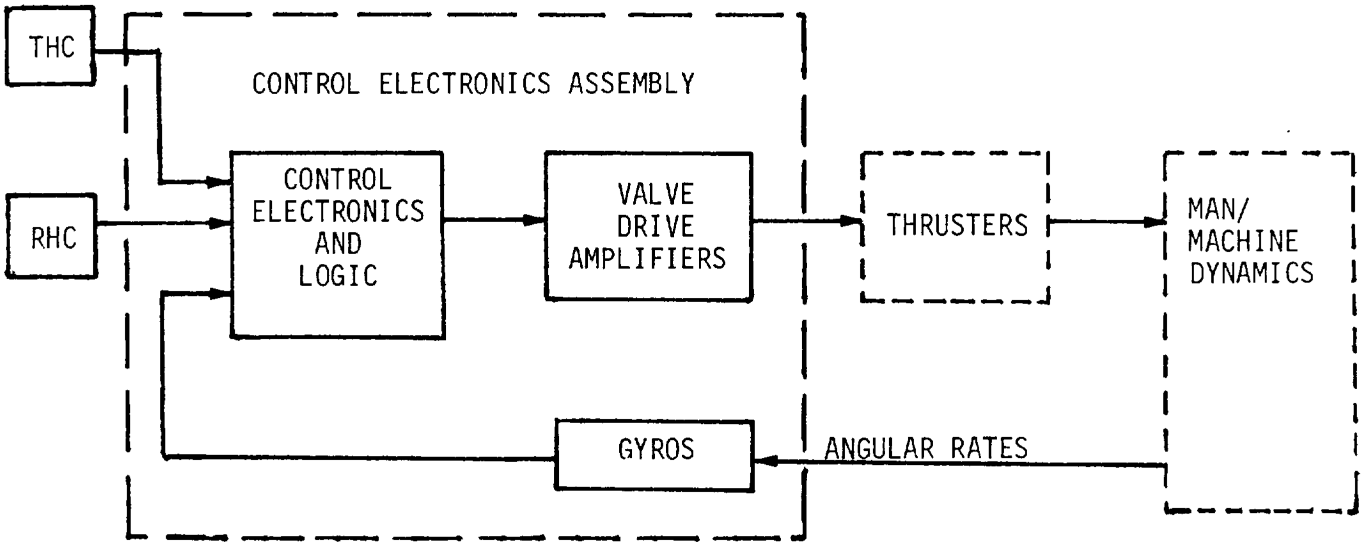


Figure 3 Maneuvering Control Subsystem

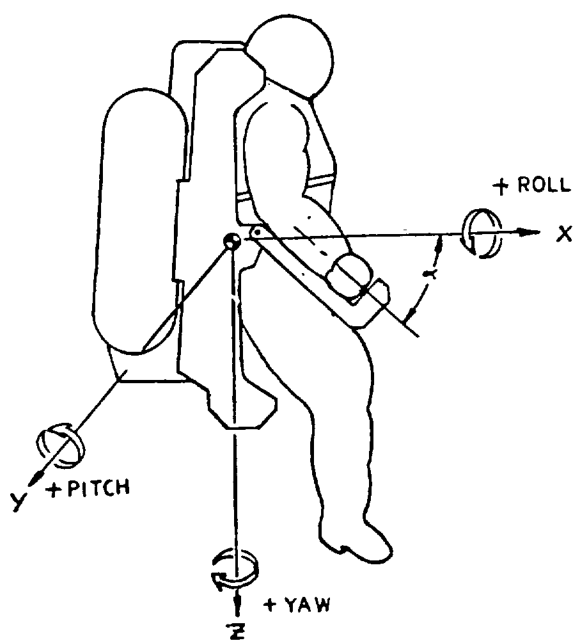
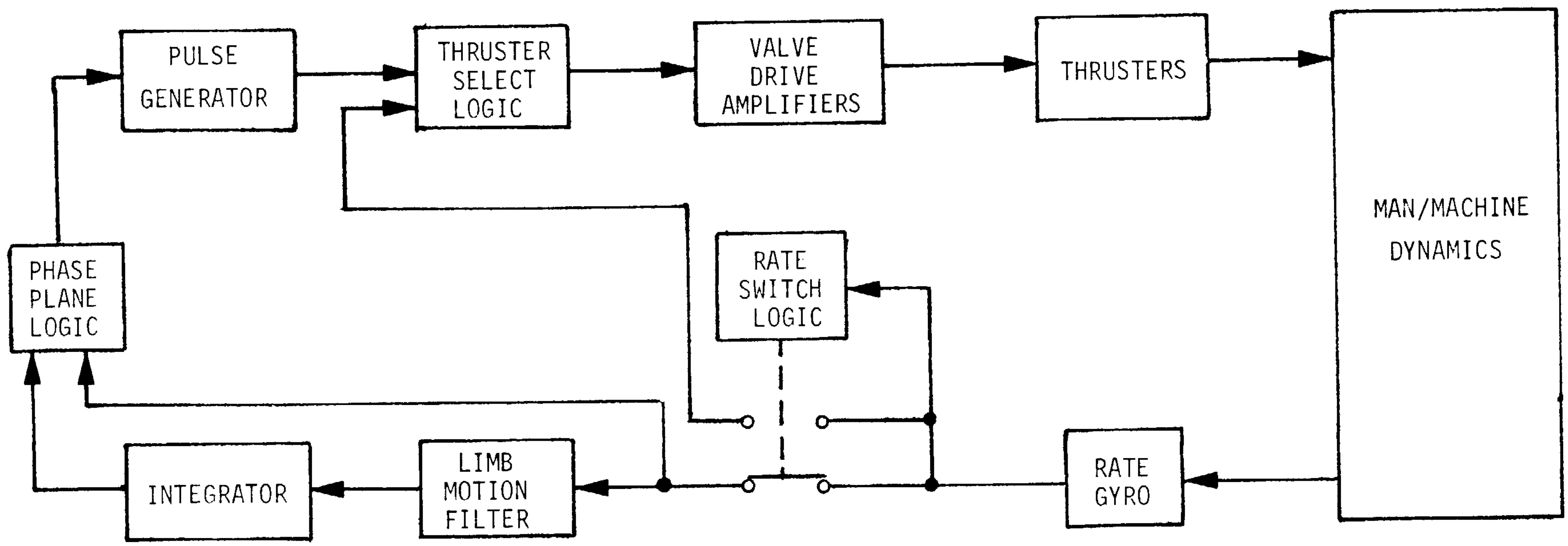
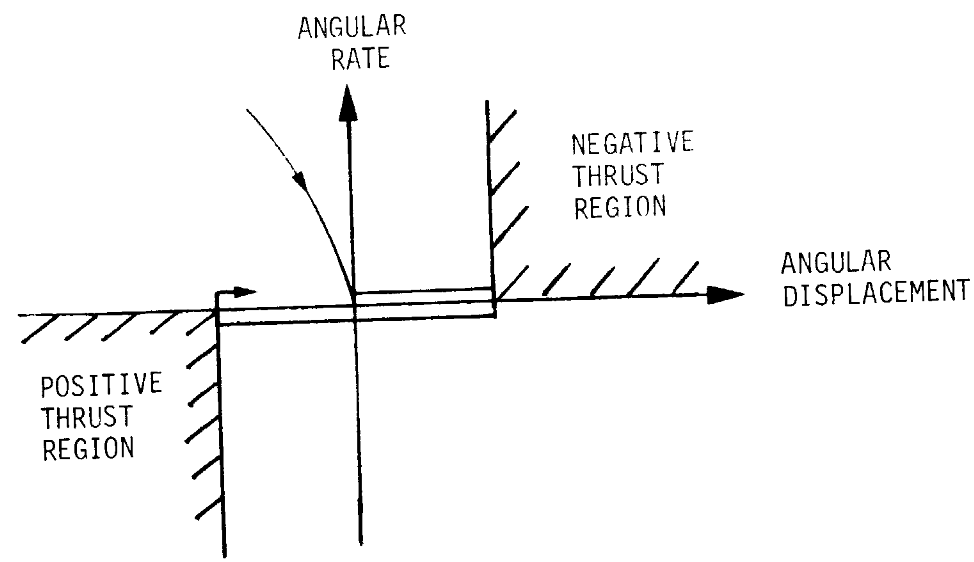


Figure 4 Reference Coordinate System



(a) Single Axis Attitude Hold Channel



(b) Convergence to Limit Cycle

Figure 5 Automatic Attitude Hold

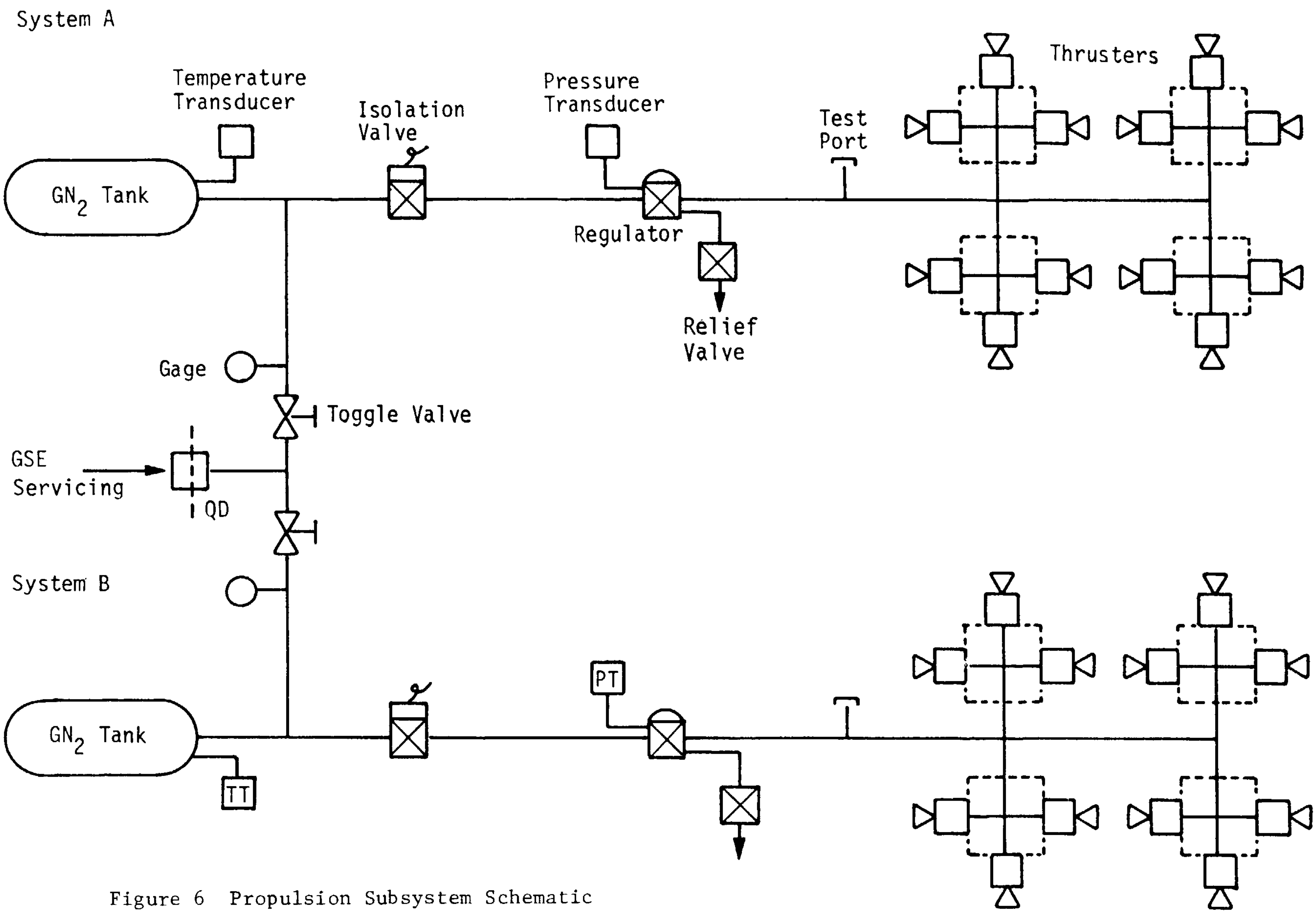


Figure 6 Propulsion Subsystem Schematic

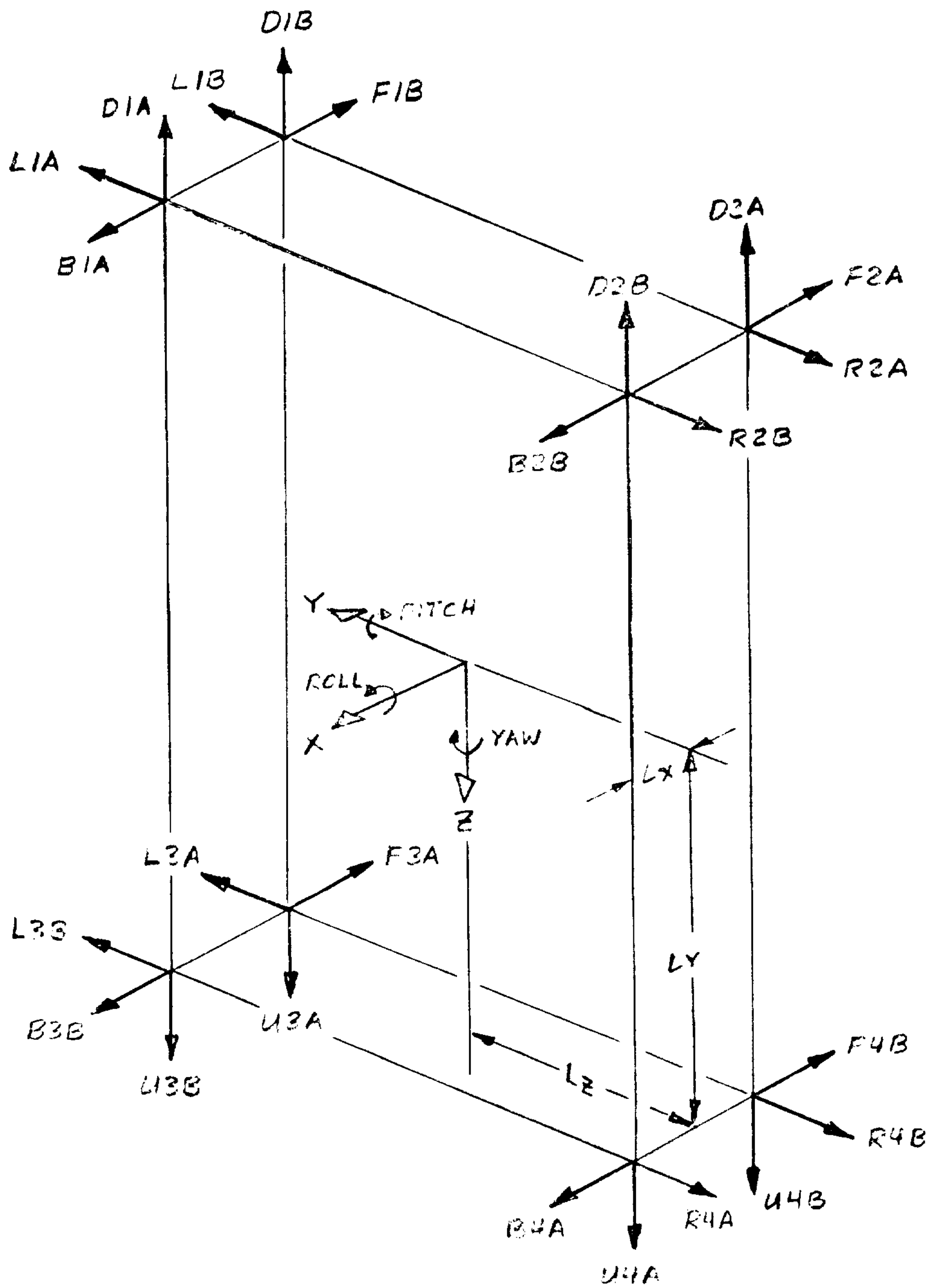


Figure 7 Thruster Triad Arrangement and Nomenclature

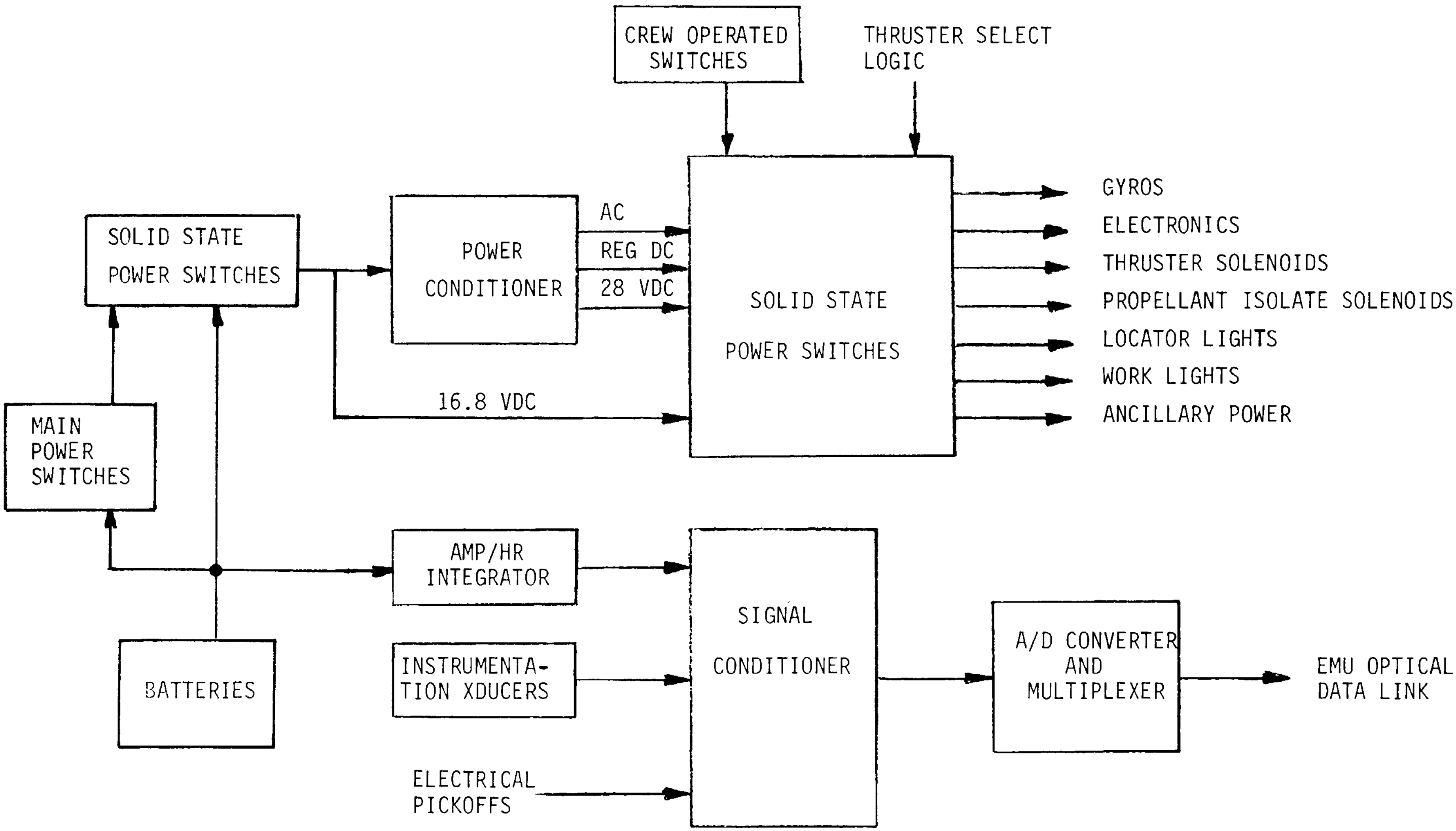


Figure 8 Electrical Subsystem Functional Diagram

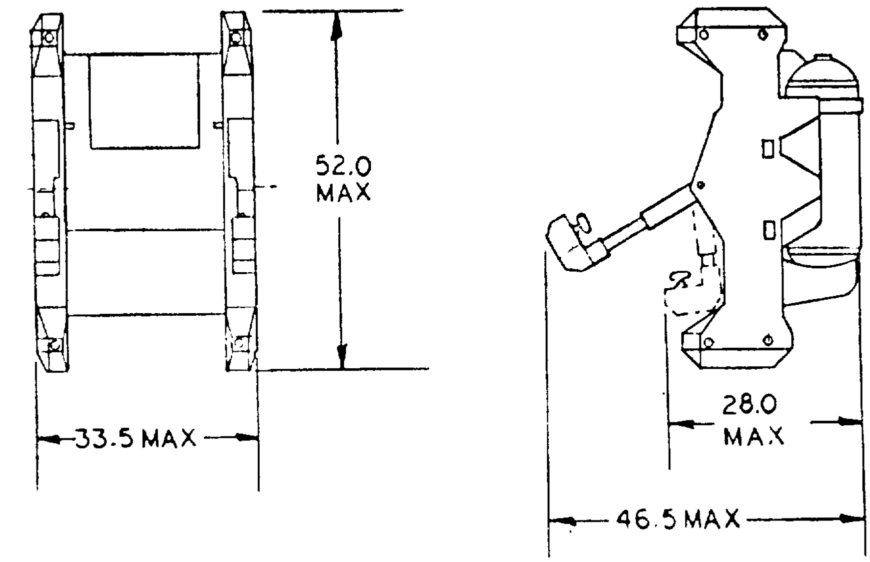


Figure 9 MMU Envelope Dimensions

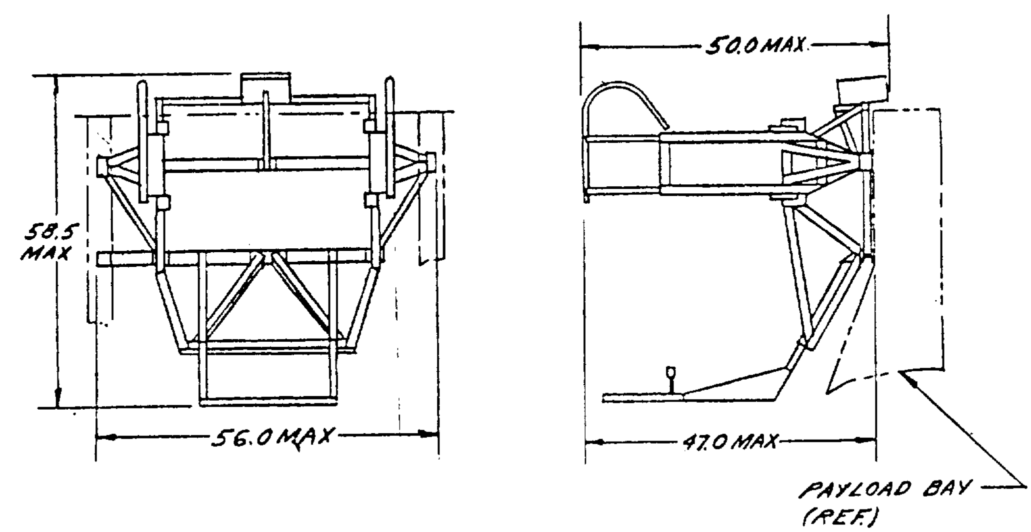


Figure 10 FSS Envelope Dimensions

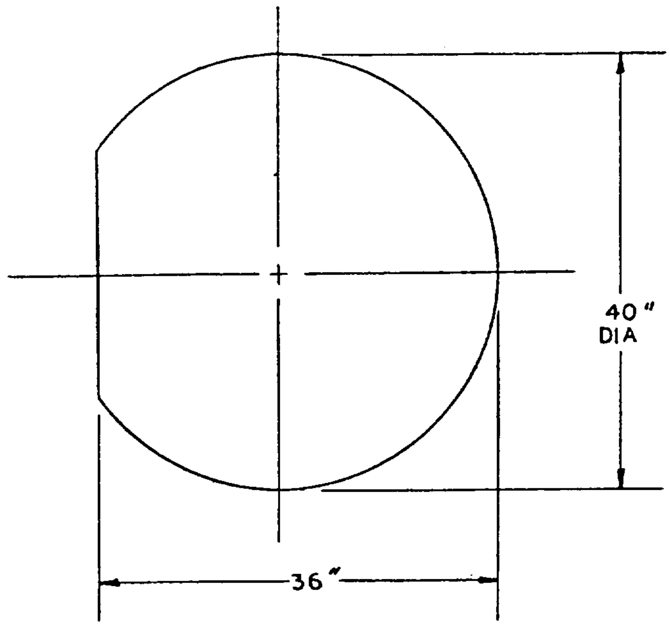


Figure 11 Orbiter Hatch Opening Dimensions

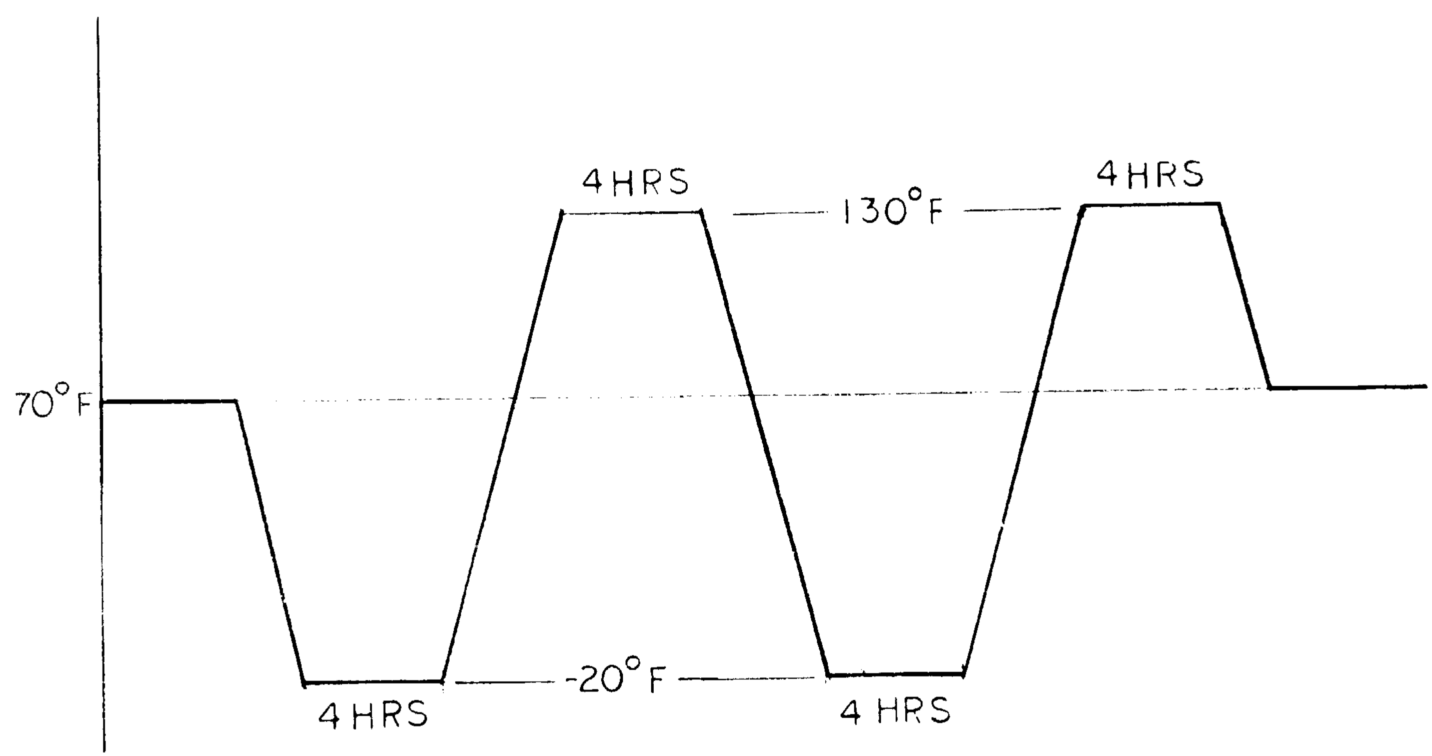


Figure 12 Acceptance Thermal Test Profile

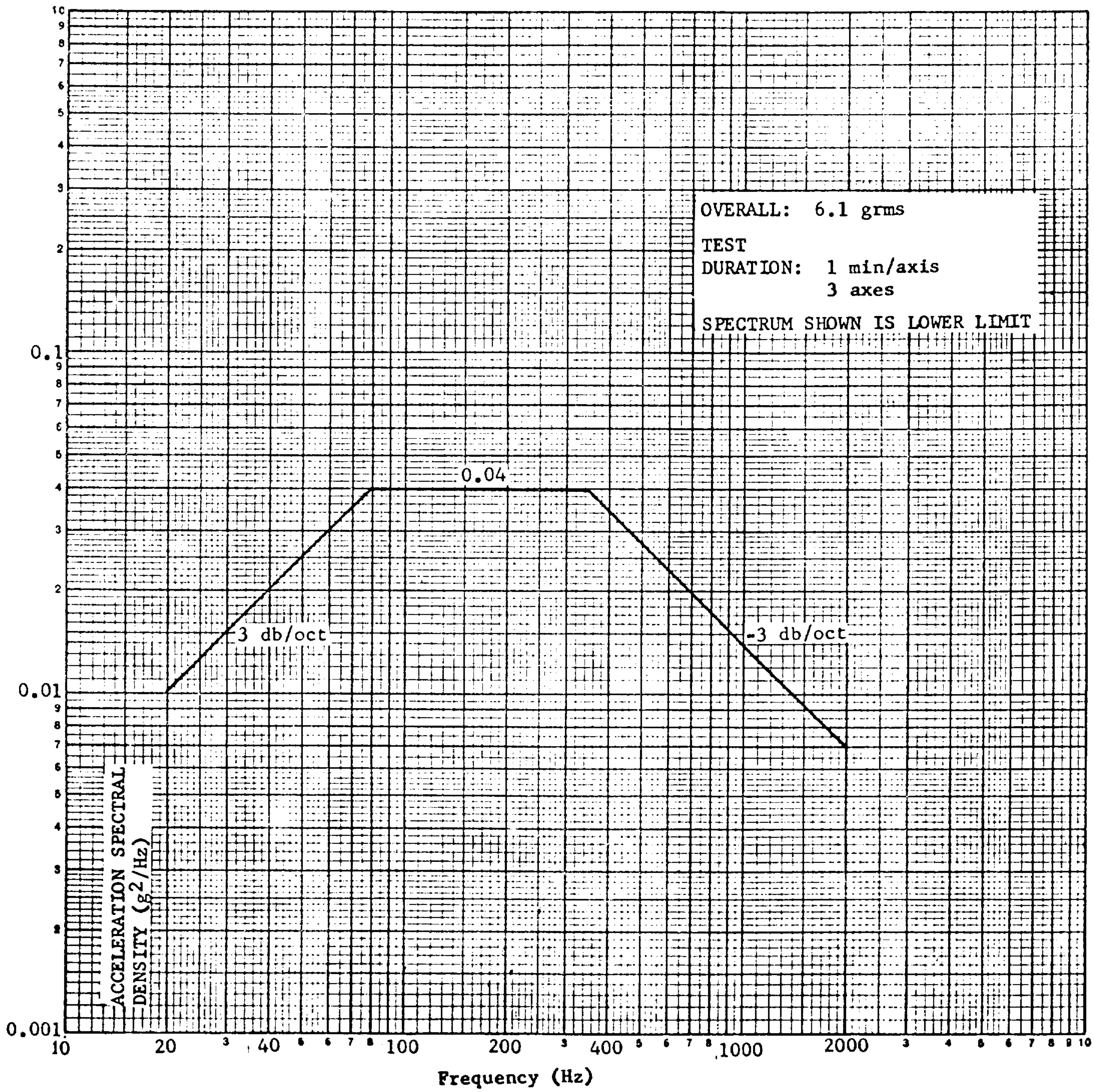


Figure 13 Acceptance Random Vibration Spectrum

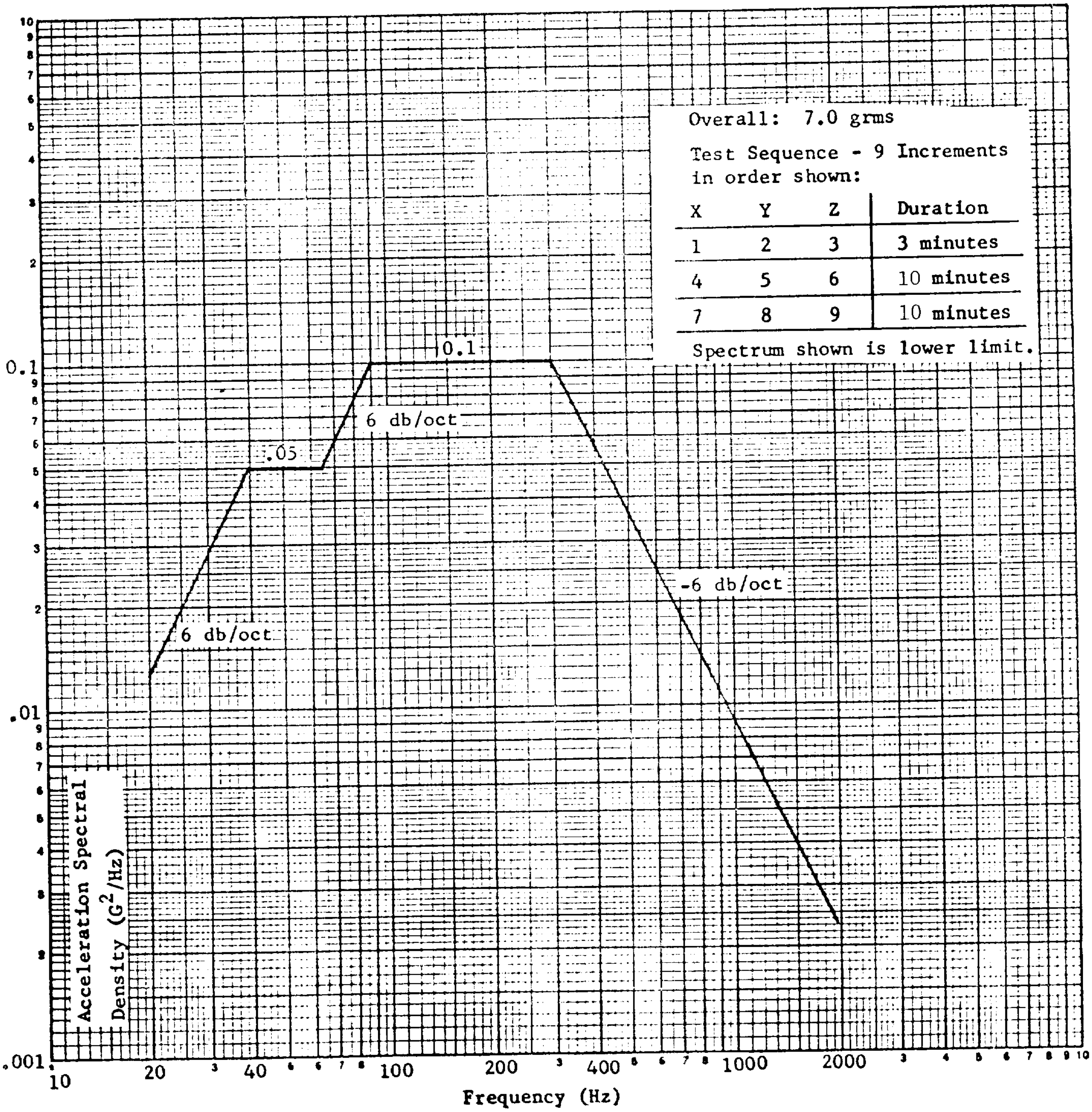
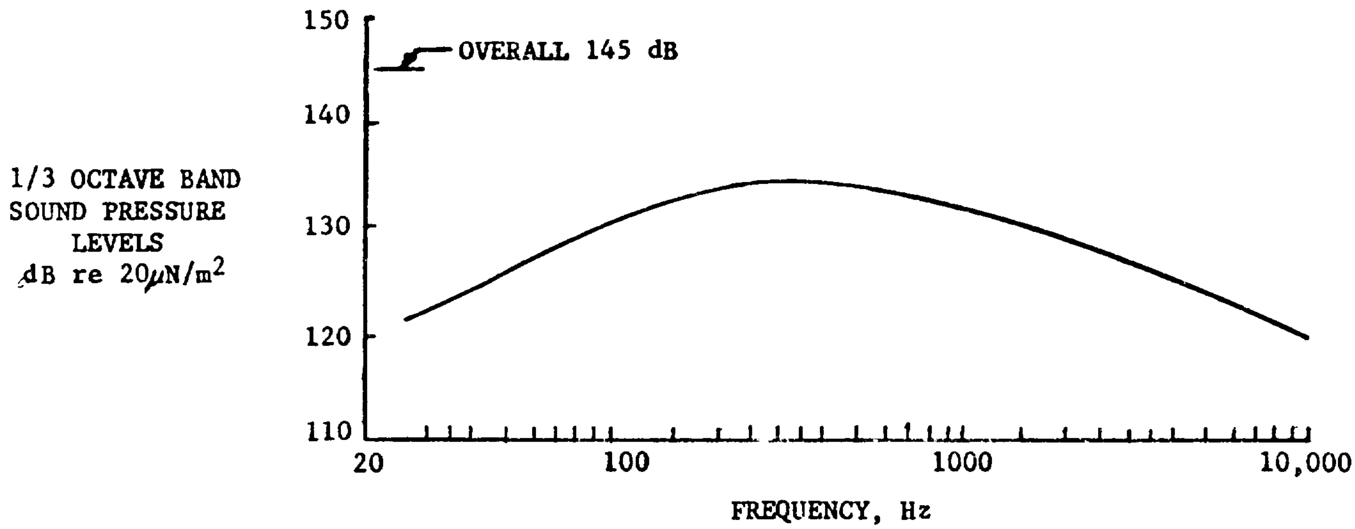


Figure 14 Launch and Reentry Vibration Spectrum



ANALYTICAL PREDICTIONS MAXIMUM ORBITER PAYLOAD BAY INTERNAL ACOUSTIC SPECTRA

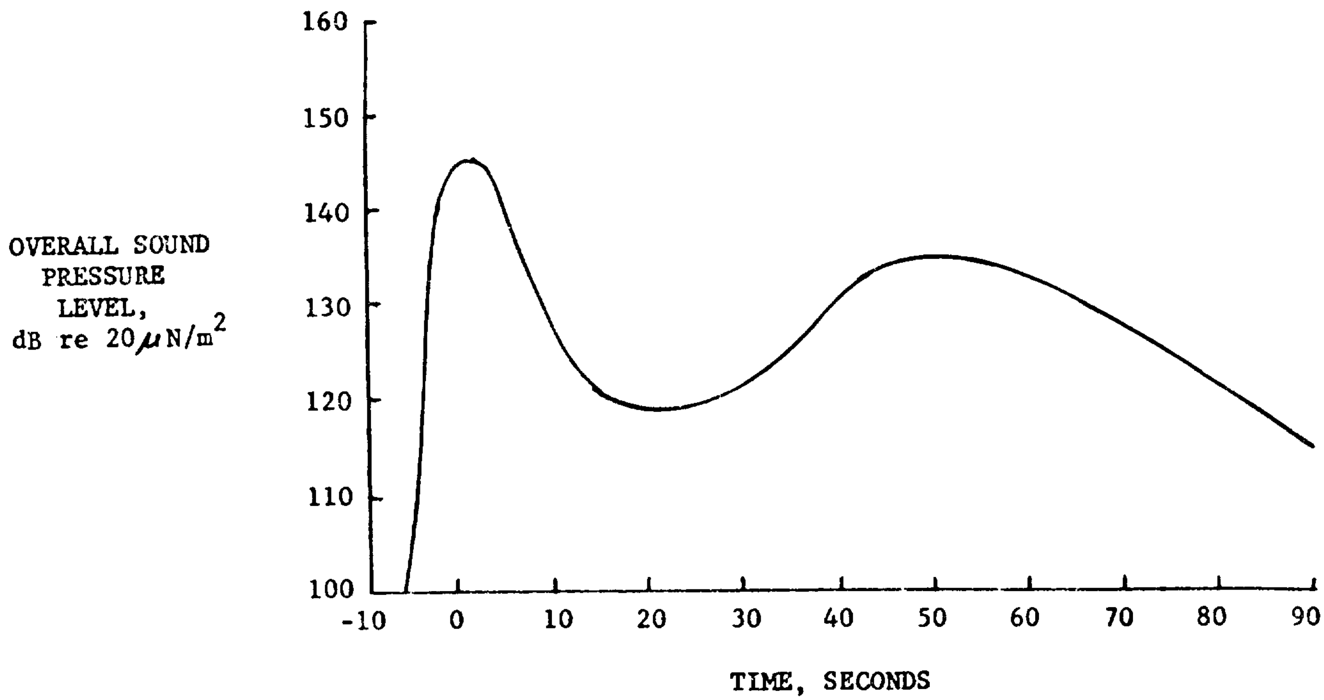
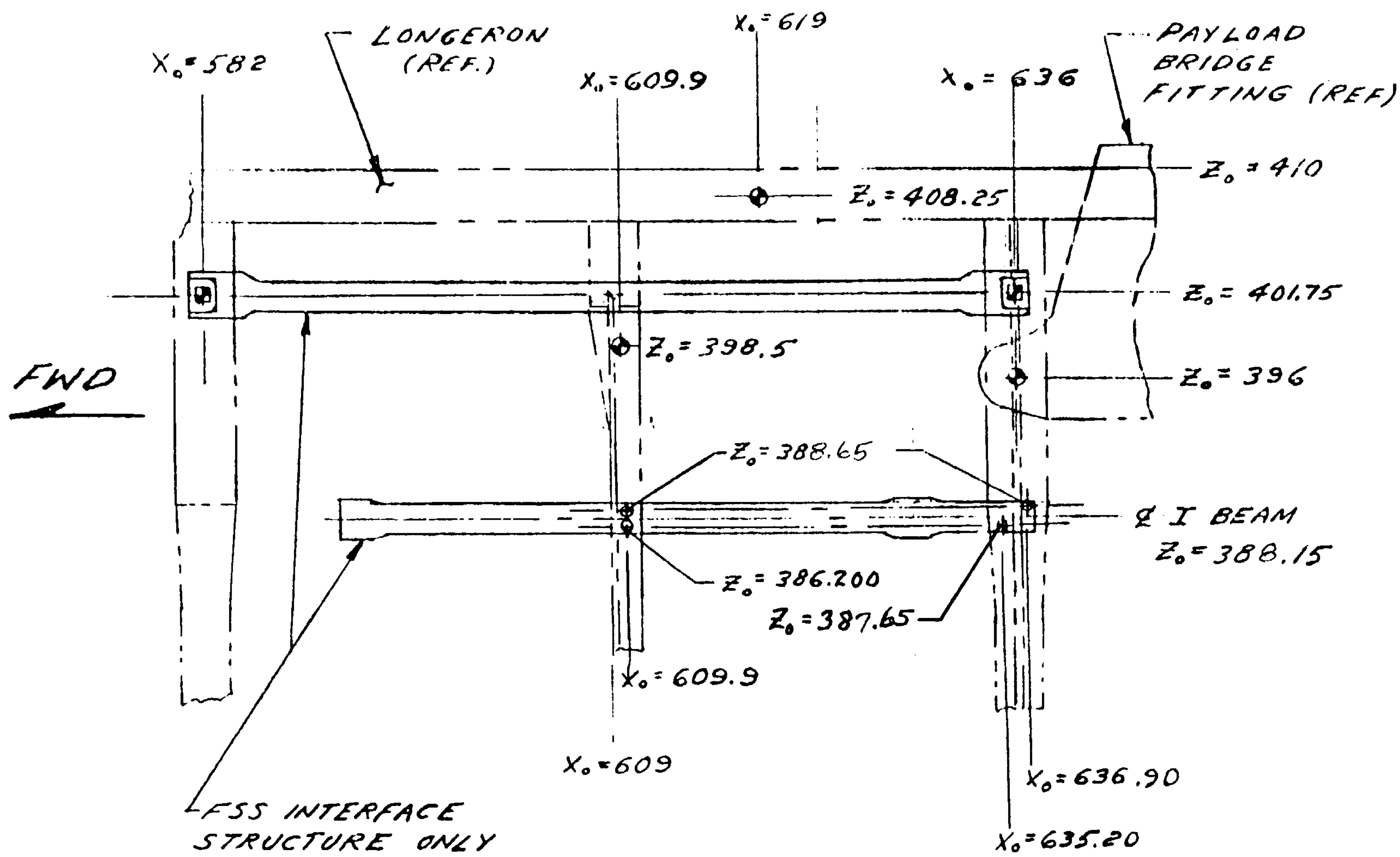


Figure 15 Payload Bay Acoustics



■ = EXISTING RI BRIDGE FITTING ATTACHMENT POINTS USED FOR FSS

⊕ = EXISTING RI BRIDGE FITTING ATTACHMENT POINTS NOT USED.

o = NEW HOLES REQUIRED IN ORBITER STRUCTURE FOR 1/4" BOLTS.

Figure 16 FSS Mounting Hole Location in Orbiter